

CREEP CELL EVALUATION AND LABORATORY TESTING
OF LARGE EVAPORITE SAMPLES.

EXECUTIVE SUMMARY

BY

Malcolm Reeves, Professor
Geological Engineering
University of Saskatchewan
Saskatoon, Sask S7N 0W0

On behalf of

THE SASKATCHEWAN RESEARCH COUNCIL

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1. ABSTRACT

An evaluation is made of the Large Sample Triaxial Test Facility (LSTTF) housed in the laboratories of the Saskatchewan Research Council (SRC) in Saskatoon. The 10 (ten) pressure cells will test very large 200 mm diameter x 400 mm cores.

Data are presented to show that triaxial strength, creep and relaxation characteristics can be determined for 200 mm diameter test specimens, with confining stresses up to at least 50 MPa, axial loads up to 700 tonnes and axial strains up to 15%.

The research potential of the facility is very extensive. The ability to test very large samples is important for coarsely crystalline materials (e.g. potash), coarse granular fills (e.g. mine tailings) and fractured rocks and soils (e.g. tills). The ability to carry out long-term tests with very large strains under computer control is particularly applicable to creep of evaporites, creep/flow of partially unconsolidated, heavy-oil reservoir rocks and consolidation of tailings and fills.

Considerable interest in the facility has been generated in the Saskatchewan potash industry and three projects involving evaporite rocks and tailings are under active consideration.

2. INTRODUCTION

Ten pressure vessels were built in the late 1970's in Saskatoon at the Saskatchewan Research Council (SRC) Laboratories. The vessels were designed as triaxial cells to test the creep behaviour of salt, potash and other similar "soft" rocks.

This report is concerned with the evaluation and calibration of the Large Sample Triaxial Test Facility (LSTTF) which was undertaken jointly by SRC and the Geological Engineering Laboratories at the University of Saskatchewan (GELUS) in 1983/84.

Funding for the evaluation was provided by the Canada Centre for Mineral and Energy Technology (CANMET), Ottawa as part of their Short Term Aid to Industry for Research and Technology (START) programme. Considerable assistance in obtaining suitable evaporite samples for testing was furnished by the Potash Corporation of Saskatchewan (PCS) and Cominco.

3. OBJECTIVES

The principal objectives of the LSTTF project were three-fold :

- (1) To evaluate the triaxial hydraulic loading systems,
- (2) To evaluate the computer control and data acquisition systems,

- (3) To evaluate the facility as a research tool for the resource based industries.

The work was largely concerned with determining the practical capabilities of the cells to perform creep/relaxation tests on "soft" rocks (mainly evaporites).

4. EQUIPMENT DESCRIPTION

Pressure vessels

There are 10 (ten) creep cells in the facility. Each pressure vessel has a height of 1350 mm, an external diameter of 600 mm and a wall thickness of 150 mm. The internal piston for axial loading is sealed with "teflon" piston rings and has a diameter of about 430 mm.

The axial load capacity is approximately 7 MN or 700 tonnes. The design specification indicates that the cells are capable of sustaining operational axial piston pressures and radial cell pressures of up to 50 MPa.

Sample jackets

The cells are designed for samples of diameter 200 mm with a length of 400 mm. The original design specified precast urethane sample jackets to isolate the test samples from the hydraulic fluid used to provide the radial confining pressure. In practice these jackets were found unsuitable and were replaced by "ecosil" (a more flexible plastic) jackets cast around the sample after the attachment of strain instrumentation.

Hydraulic control system

The radial and axial cell pressures are completely independent and can be computer controlled. Pressure transducers sense pressure changes and adjustments can be made by actuating solenoid valves. The design specifications require that pressures be maintained constant for extended periods to within ± 0.4 MPa.

Deformation monitoring system

The current method of monitoring vertical strain was arrived at after several trials. It involves the direct cementation of small, metal, circumferential shells to the sample surface at three equally-spaced points near the ends. These shells were threaded so that a rod, to which the potentiometers were attached, could be firmly anchored. The ecosil sample jacket was cast around the shell attachments with the rod passing through the jacket.

Horizontal strains are monitored by resistance wire strain gauges. Attempts to develop "girth" monitors using spring loaded bands and resistance wire wraps have made little progress to date. The estimation of volumetric strains from cell-oil volume changes has yet to be perfected.

Computer logging and control systems

An IBM-PC computer (or compatible) with an on-board Tecmar TM40 logger controller card is used for all logging and control functions in the laboratory. The data acquisition and control system software has been fully tested for single cell operation.

5. TEST SPECIMENS

Aluminium test cylinder

The aluminium test-piece comprised a 250 mm diameter x 300 mm cylinder which was instrumented with 6 x 50 mm length resistance wire strain gauges (3 vertical, 2 horizontal) placed symmetrically on the cylinder surface at about the approximate mid-point in the axial direction. The test cylinder was tested for elastic response by loading in the 400 tonne Tinius-Olsen compression machine at GELUS. The derived elastic parameters agreed very closely with the published values.

Evaporite test specimens

Evaporite test specimens were obtained with a 200 mm internal diameter carbide "toothed" coring bit which proved an excellent cutting tool with almost 100% recovery.

The rough cores were wrapped in heavy duty plastic sheeting with one end exposed and cut with a 900 mm diameter diamond saw blade. Water was used as a cutting lubricant on the "offcut-side" of the blade only.

The sawn faces obtained in this way were close to parallel. Grinding to give more precisely parallel faces would be desirable for material property testing, but for the series of tests designed to evaluate the test rig, non-parallel faces were deliberately used in an attempt to induce asymmetric loads and check the effectiveness of the hollow-ground self levelling platens.

Normally cores were instrumented with three axial potentiometers together with three axial and three diametral resistance-wire strain gauges cemented to the rock surface.

6. CALIBRATION TESTS

Calibration tests

A number of uniaxial tests were carried out on the 400 tonne capacity Tinius-Olsen compression machine at GELUS, to determine the load-deformation behaviour of both the aluminium test cylinder and the evaporite test specimen R1. Similar tests were repeated in the LSTTF to check that the axial piston loads were fully transferred to the test specimen.

The correspondence of test results between GELUS and LSTTF, together with the direct measurement of piston friction, gave some confidence that the LSTTF cell transfers the axial load to the test specimen without significant losses in friction.

7. PRESSURE TESTS

Pressure test series #1-#3

A series of pressure tests were devised to discover and rectify any significant leaks in the pressure vessel and hydraulic "plumbing" systems. The tests were carried out with the aluminium test cylinder acting as a "load cell".

The pressure test series lead to the elimination of the small, temperature-sensitive, accumulators from the hydraulic circuits in favour of direct control using the main accumulator. Feedthrough design for sensor cables was also modified.

With the modified systems it is found that the magnitude of the daily pressure loss is insignificant. The pressure test series have shown that the cells can be maintained at constant pressure over extended periods and that very few pressure adjustments are necessary.

8. TRIAXIAL LOAD TESTS

Triaxial load test series #4

The first series of load tests was carried out on the aluminium test cylinder. The earliest tests at low stress levels show some uneven load distribution patterns but this tendency disappeared as the self-adjusting platen mechanism became "worn-in". Even loading was achieved for all the tests at high stress levels.

Triaxial load test series #5

A series of stress-strain response curves were determined for the aluminium cylinder at constant axial pressure by incrementing the confining pressure to restore hydrostatic conditions.

The results clearly demonstrate behaviour consistent with the published elastic properties of aluminium. These tests together with series #4 gave confidence in the even application of both axial and cell pressures.

Triaxial load test series #6

This series of tests was carried out on potash core R1. The tests were designed primarily to evaluate the performance of the LSTTF for large specimen strains.

Potentiometers used in test series #6 were attached to metal bands around the outside of the jacket, close to the upper and lower sample ends. These attachments were subsequently discovered to be prone to slippage, thus recording an overestimate of strain.

Triaxial load test series #7

This series of tests was carried out on potash core C1. These tests were designed primarily to evaluate the comparative performance of the axial gauges and potentiometers over a wide range of stress and strain conditions.

Comparison of vertical strain gauge and pot results showed (Fig.1) that in the later data for test series #7 the desired consistency is obtained. At large strains, the attachment bands for the pots were found to severely restrict the diametral expansion of the core ends. To avoid this problem in future tests, a new "shell" attachment procedure was adopted.

Triaxial load test series #8

This series of tests was carried out on potash core C2. These tests were designed primarily to obtain a more complete set of diametral strain measurements and to determine the triaxial strength of core C2 under conditions of rapid loading.

The most important finding of test series #8, the deteriorated state of the solenoid valve "o"-ring seals, was not anticipated. Following this test, a series of failures of the old (6-8 years) "o"-rings delayed the testing of the computer control systems.

The short test series #8 gives an estimate of the shear strength of core C2 under fairly rapid loading conditions. Core C0 (tested uniaxially in GELUS), C1 and C2 were all loaded at strain rates

of about 10^{-5} /sec*. The failure stresses are plotted in octahedral shear stress - mean stress space in Fig.2.

Triaxial load test series #9

This series of tests was carried out on potash core C3. These tests were designed primarily to compare the performance of axial gauges and potentiometers, following the development of a method of attaching the pots directly to the core ends by mounting small circumferential plates or "shells".

The test series established reasonable comparability of strain gauge and potentiometer displacement data for both loading and creep phases of the testing. The erratic behaviour of the vertical strain gauges (Fig.3) during rapid creep highlights the advantages of the pot system which, in contrast, yielded very consistent data.

Triaxial load test series #10

This final series of tests was carried out on potash core V1. The tests were designed primarily to evaluate the creep/relaxation characteristics of core V1.

The creep test is the longest test carried out in the LSTTF and shows steady-state creep with little sign of "strain-hardening" after more than 1000 hours. The steady creep rate (Fig.4) is about 350 microstrains per day or 4×10^{-9} /sec and is close to the instrumental sensitivity for hourly variations.

9. COMPUTER LOGGING AND CONTROL

Power failure protection

To ensure continuity of supply all laboratory systems may be powered from d.c. batteries through a surge protector and an inverter, the battery being continually charged from the a.c. mains.

Data signals

Data signals are defined as readings from sensors which are logged. All pots, LVDT's, pressure transducers and strain-gauges provide data signals which the computer "reads" or "receives".

A typical configuration of data sensors involves three axial pots, five horizontal strain gauges and five hydraulic pressure sensing transducers. Many of these data signals require conditioning before they are read by a logging device.

* This notation should be read as 10 raised to the power of -5 per second.

The Tecmar TM40 logger/controller card, used in an IBM-PC or COMPAQ computer, carries out all necessary control and logging functions. With external signal conditioning, the TM40 card can sample at the rate of 40 kHz (40,000 channels per second).

Logging software

The software to perform logging functions is very simple. Since fast execution of code is not essential, the programs were written in Microsoft BASICA.

The interval between readings can be set to a constant value or can be based on the rate of change of sensor signals. This prevents the accumulation of huge amounts of irrelevant data when slow consistent variations are logged.

Control signals

Control signals are defined as those "written" or "sent" by the computer to cause some device to operate. The only control signals in the triaxial cell system are five logical open/close instructions to solenoid valves in the hydraulic circuits.

Control signals are output from the Tecmar controller through an 8-bit parallel port. The solenoid valves require 110 volts a.c. supply to operate and the switching is achieved through an eight channel opto-isolated power driver card.

Control software

The software to operate the control circuitry, in common with the logging software, is relatively simple. It is also written in Microsoft BASICA since the speed of response is not critical.

The routines fall into two distinct groups. Switch routines to open and close switches; and control routines to decide which switches to open or close. The control routines call some simple logging routines for information upon which to base decisions.

Data storage/retrieval/display

A series of auxiliary, post-test, processing routines have been written which tabulate and plot various logged parameters or functions of logged parameters.

Software documentation

The control/logging package is written in a form which can be readily adapted for other hardware configurations. It will log up to 16 analogue inputs and operate up to 8 control devices.

Care has been taken to isolate hardware dependent code so that the software is hardware independent and transportable. The final version of the software will be self-documenting and menu-driven.

10. RESEARCH APPLICATIONS

Applications to Energy and Mining research

The Large Sample Triaxial Test Facility (LSTTF) is very versatile. The unique feature of the laboratory is the very large size of the test specimens that can be handled. The scale dependence of many of the physical properties of rocks and soils is well established and the ability to test large specimens is very important in :

- (a) coarsely crystalline rocks,
- (b) coarsely granular tailings and fills and
- (c) fractured rocks and soils

A second major feature of the LSTTF is the ability to carry out very long-term tests under computer control so that virtually any "stress path" for a test may be specified.

Evaporite mining applications

The most obvious application is the one for which the laboratory was originally designed; to determine the long-term strength of pillars and stability of openings in coarsely crystalline potash.

Data from long-term creep and/or relaxation tests enable the reliable prediction of stress redistribution. This is essential information for the design of extraction methods which ensure both commercial profitability and mine safety.

Mine tailings and backfill applications

Many mining operations, including that of potash generate large volumes of tailings (waste) which may contain very coarse crystals, particles or fragments. The behaviour of these materials, when used as fills on the surface or underground, is a critical design parameter.

With minor modifications, the LSTTF can perform drained triaxial consolidation/creep tests on such materials.

Open pit mining applications

Many open pit mines in Canada are initially cut through glacial deposits. Many of the older tills are heavily fractured and both their strength and drainage characteristics are strongly dependent on the properties of the fracture network as opposed to the intact material. In many near-surface excavations, the consolidated rock is likely to be fractured and jointed and may also be tested in the LSTTF.

Tests on small samples do not sample the fractures and tend to give properties representative of the intact matrix. The LSTTF has the potential to determine strength and drainage characteristics for fractured rock and soil masses on a scale which might reasonably be expected to be representative of both fracture and matrix characteristics.

Heavy oil industry applications

Many of the heavy oil and tar sand deposits of Western Canada are essentially cohesionless soils held together by very high viscosity hydrocarbons. As a result, when attempts are made to produce the oil, there is a tendency for the whole reservoir to "flow" rather than for the oil to flow through the reservoir. Similarly when the tar sands are mined, there is a distinct tendency for the formation to creep.

The LSTTF can determine the creep/flow characteristics over a wide range of triaxial stresses. With a very minor modification, the facility can perform such tests over a range of temperatures from 0 to at least 50 degrees Celsius.

11. CONCLUSIONS AND RECOMMENDATIONS

Achievement of objectives

The three prime objectives of the project have been substantially achieved. The test facility is viable and one of the ten cells is fully operational (and in virtually continuous operation).

Proposals for further research and development

The current phase of work has served to reveal the huge potential of the LSTTF as a research tool. A single cell is now operational on a research basis but additional capital equipment and further development is necessary before the laboratory can undertake a substantial test program.

The major requirements are :

- (1) Employment of a full-time laboratory technician responsible for the day to day maintenance and operation of the facility.
- (2) Purchase of a computer logger/controller system dedicated to the facility.
- (3) Further software development to operate more than a single cell and extensive reliability trials for the current control/logging software (which is essentially untested on multiple cells).
- (4) Purchase of a high volume accumulator rated to 70 MPa with capacity to run up to 5 cells.
- (5) Commissioning of 2 additional cells to incorporate the modifications made on the first research cell.
- (6) Modifications to enable control of cell temperature and measurement and control of pore fluid pressures.

FIG. 1 Strain-time curves for
 triaxial creep test #7.5:
 potash core C1.

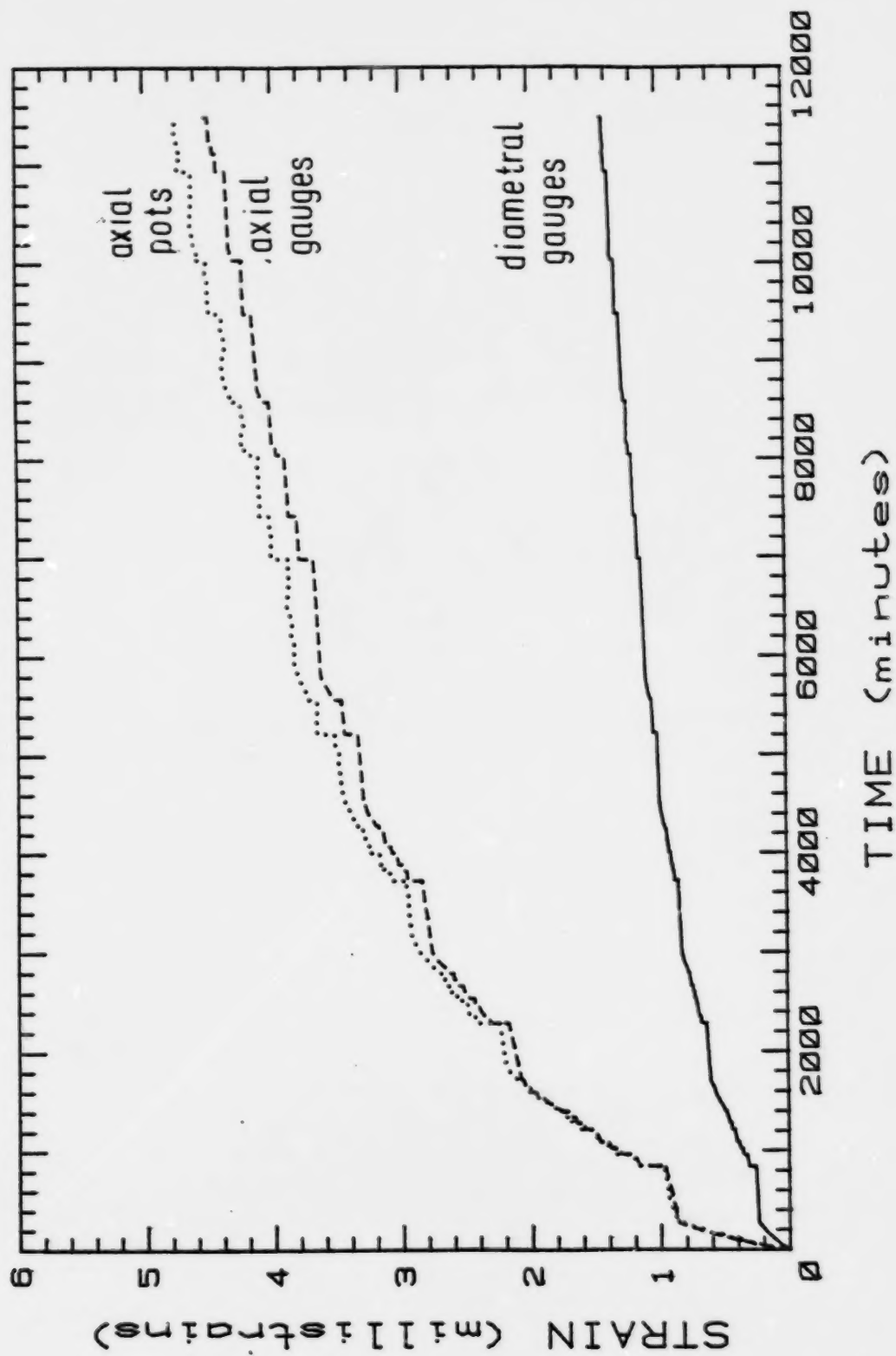


FIG. 2 Stresses at failure and stress paths for potash cores C0, C1 and C2.

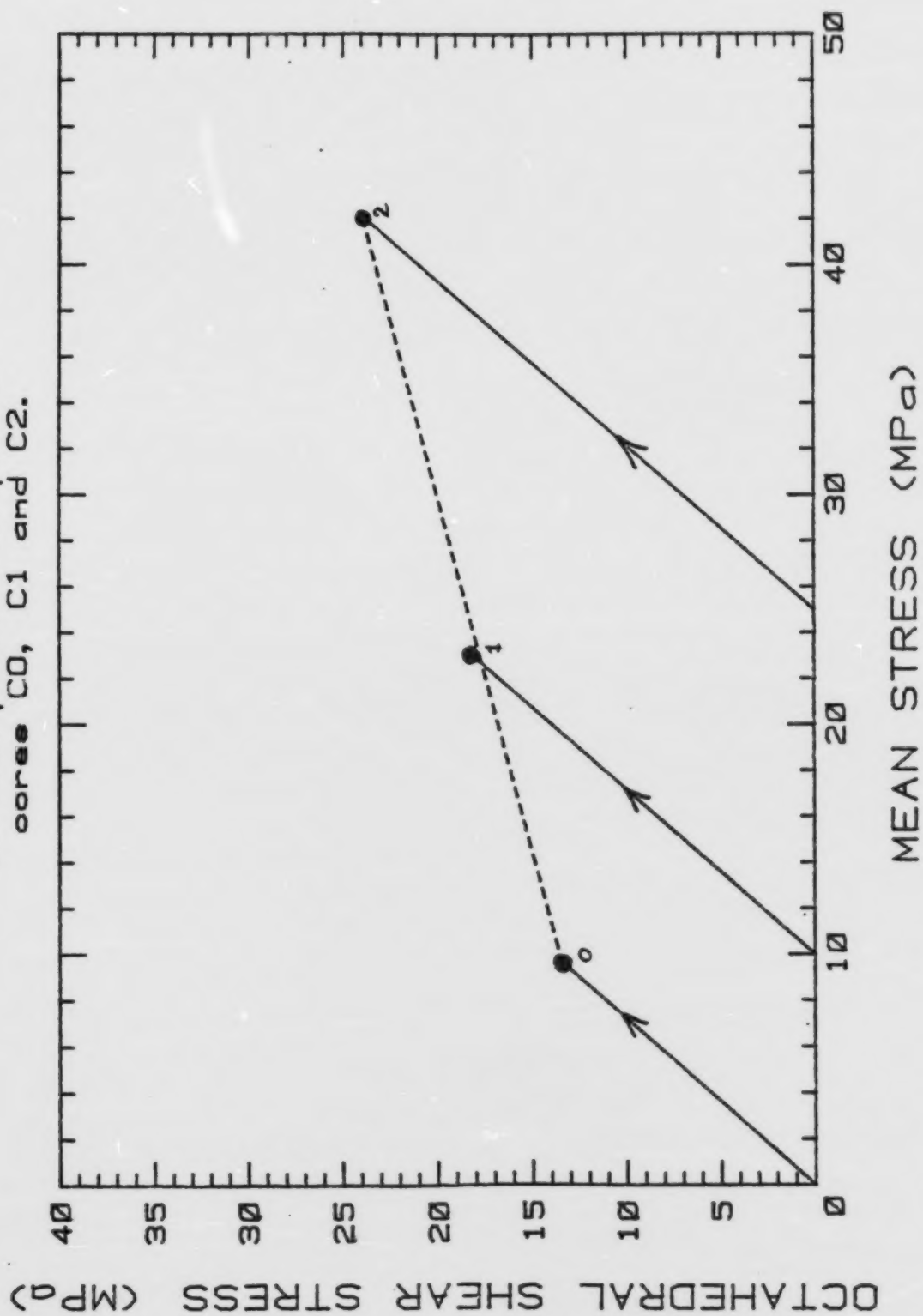


FIG. 3, Strain-time curves for
triaxial creep test #9.1:
potash core C3.

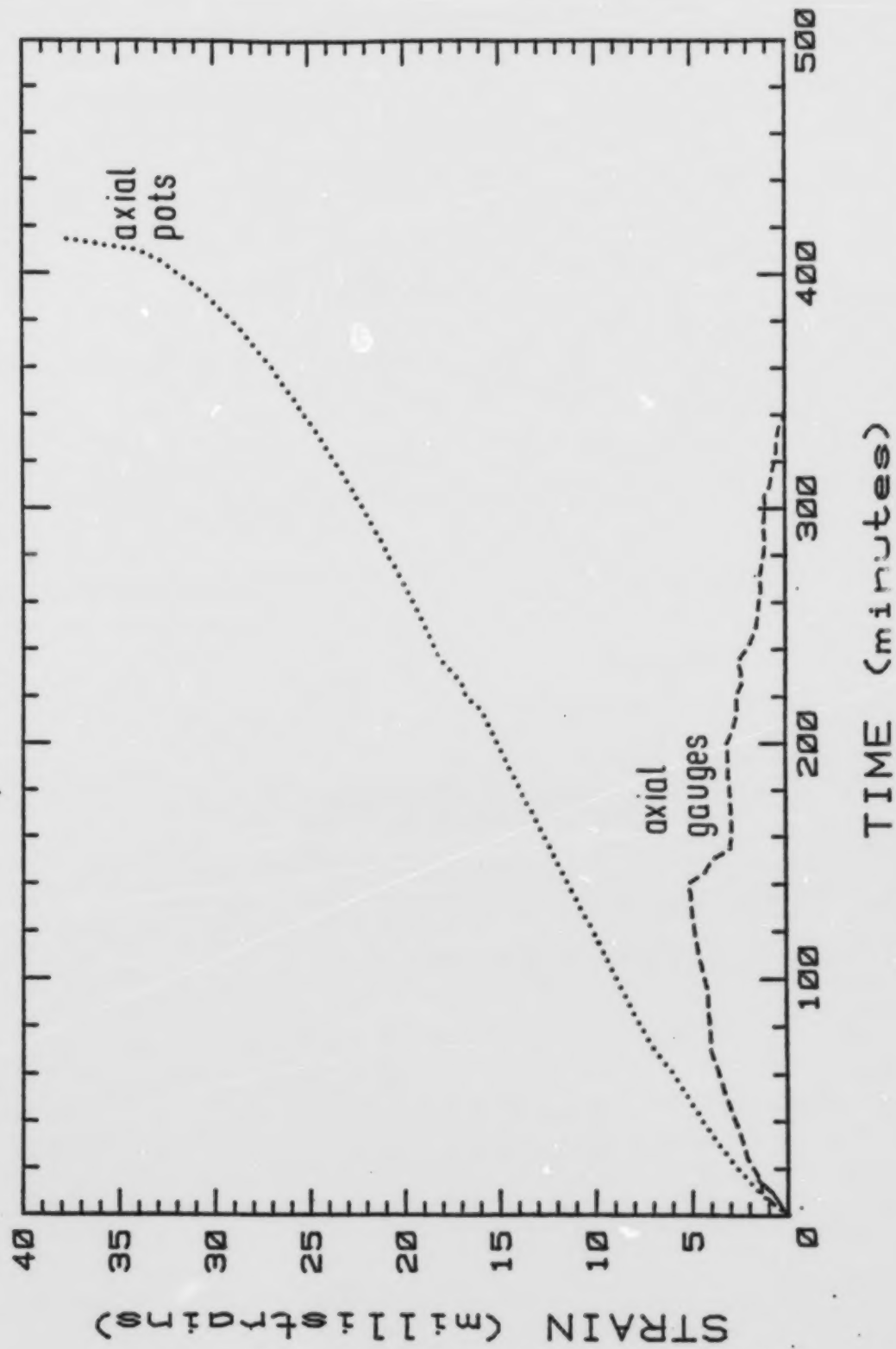
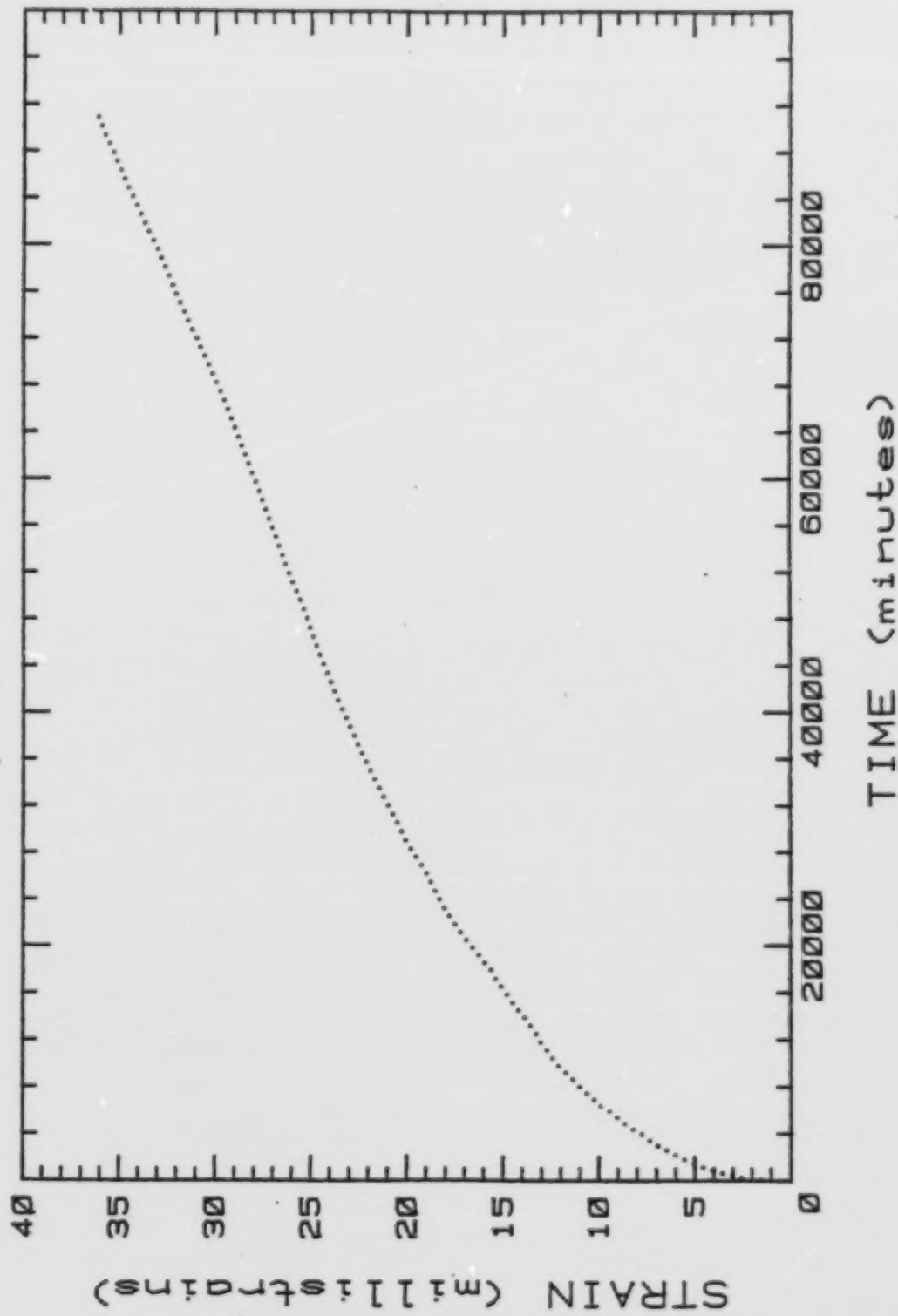


FIG. 4, Strain-time curve for
triaxial creep test #10.1,
potash core V1.



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LARGE SAMPLE TRIAXIAL TEST FACILITY EVALUATION

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1. ABSTRACT

An evaluation is made of the Large Sample Triaxial Test Facility (LSTTF) housed in the laboratories of the Saskatchewan Research Council (SRC) in Saskatoon. The 10 (ten) pressure cells will test very large 200 mm diameter x 400 mm cores.

Data are presented to show that triaxial strength, creep and relaxation characteristics can be determined, for 200 mm diameter test specimens, with confining stresses up to at least 50 MPa, axial loads up to 700 tonnes and axial strains up to 15%.

A series of design modifications have proved necessary to reach this stage. The hydraulic-circuit control system and the strain monitoring system have been extensively changed from the original design. Improved accuracy for strain and pressure instrumentation and further development of measurement techniques for volumetric strains are recommended.

Creep data from the laboratory are consistent with the published data for potash bearing evaporite rocks and a "steady" creep rate of 350 microstrains/day (4×10^{-9} /sec)* has been sustained for an extended period (> 60 days). Controlled creep tests have been carried out for periods exceeding 60 days. The maximum controlled strain rate is estimated to be 1.25×10^{-4} /sec and is limited by the speed of response of the solenoid valves in the hydraulic circuits. Constant strain (relaxation) tests are potentially possible under computer control but such tests have yet to be carried out on 200 mm dia. cores. The capacity to carry out such tests is fully established for 100mm dia. cores using an identical data acquisition and control system in the Geological Engineering Laboratories at the University of Saskatchewan (GELUS). The sensitivity of the existing (LSTTF) pressure sensors which control the load is equivalent to a sample stress increment of 0.4 MPa, although this could be improved substantially.

Only simple modifications to the equipment are necessary to enable the monitoring and control of cell temperature and pore fluid pressures. It will then be possible to extend the capabilities of the LSTTF to encompass triaxial consolidation and controlled temperature creep tests.

The research potential of the facility is very extensive. The ability to test very large samples is important for coarsely crystalline materials (e.g. potash), coarse granular fills (e.g. mine tailings) and fractured rocks and soils (e.g. tills). The ability to carry out long-term tests with very large strains under computer control is particularly applicable to creep of evaporites, creep/flow of partially unconsolidated, heavy-oil reservoir rocks and consolidation of tailings and fills.

Considerable interest in the facility has been generated in the Saskatchewan potash industry and three projects involving evaporite rocks and tailings are under active consideration.

* This style of notation should be read as 4 times 10 to the power of -9 strains per second.

2. INTRODUCTION

Ten pressure vessels were built in the late 1970's in Saskatoon at the Saskatchewan Research Council (SRC) Laboratories. The vessels were designed as triaxial cells to test the creep behaviour of salt, potash and other similar "soft" rocks. The equipment remained unused and untested from 1978 to 1983, after completion of the construction.

This report is concerned with the evaluation and calibration of the Large Sample Triaxial Test Facility (LSTTF) which was undertaken jointly by SRC and the Geological Engineering Laboratories at the University of Saskatchewan (GELUS) in 1983/84.

Funding for the evaluation was provided by the Canada Centre for Mineral and Energy Technology (CANMET), Ottawa, as part of their Short Term Aid to Industry for Research and Technology (START) programme. Considerable assistance in obtaining suitable evaporite samples for testing was furnished by the Potash Corporation of Saskatchewan (PCS) and Cominco.

A detailed knowledge of the time-deformation characteristics of the materials surrounding mine excavations is vital for the safe and economic design of underground openings and support pillars. LSTTF provides such information for both intact rock and potential backfill material.

Considerable interest in the facility has been expressed by a number of potash mining companies and three testing projects are under active consideration for 1985. These include controlled strain-rate tests on potash rocks, conventional creep tests on carnallite and creep/consolidation tests on salt tailings.

The future of the facility depends on the industries' perception of the cost-effectiveness of laboratory tests on large samples. Costs on a per sample basis are not insignificant (at least \$5000), but if such tests can be shown to provide a reliable database for practical design of mine openings, then the LSTTF can become a self-supporting service to the industry. A through-put of about 20 samples per annum would be necessary for economic self-sufficiency and this implies a minimum of 3 pressure vessels in full-time operation (allowing 60 calendar days per sample).

3. OBJECTIVES

The principal objectives of the LSTTF project were three-fold :

- (1) To evaluate the triaxial hydraulic loading systems,
- (2) To evaluate the computer control and data acquisition systems,
- (3) To evaluate the facility as a research tool for the resource based industries.

The work was largely concerned with determining the practical capabilities of the cells to perform creep/relaxation tests on "soft" rocks (mainly evaporites).

3.1 Loading system evaluations.

The loading system evaluation comprised a series of tests designed to determine the following parameters :

- (a) Pressure tightness, the rate and magnitude of pressure drops due to minor leaks, creep in pipes and fittings, thermal expansion/contraction etc. Both axial and radial hydraulic circuits were tested.
- (b) Piston friction, the minimum pressure increment necessary to initiate movement of the axial load piston.
- (c) Load capacity (axial and radial), the maximum load that the system can apply in practical operation.
- (d) Load precision (axial and radial), the minimum detectable pressure change in the hydraulic loading systems.
- (e) Load rate (axial and radial), the time required to make an incremental adjustment to the load under manual and computer control.

3.2 Control and logging system evaluations.

To prove the feasibility of data acquisition and pressure control over the extended periods required for creep/relaxation tests a series of control and logging functions were developed. The project aims in this respect were :

- (a) To acquire (log) analogue signals from LVDT's, potentiometers, strain gauges and pressure transducers.
- (b) To condition (scale and amplify) the above signals.
- (c) To use processed signals to exercise experimental control.

- (d) To provide some online display and/or processing capability.

In addition, the following parameters were to be determined :

- (e) Strain capacity (axial and radial), i.e. the maximum strains that can be measured.
- (f) Strain precision (axial and radial), i.e. the minimum strain increments that can be detected.
- (g) Strain rate, i.e. the minimum strain rate that can be controlled either manually or by the computer.

3.3 Research potential evaluation.

The final objective was to evaluate the value of the test facility as a research tool for the resource based industries (principally mining). The aims in this respect were :

- (a) To determine the range of tests which can be performed using the hydraulic cells.
- (b) To determine the range of earth materials which can be tested.
- (c) To determine the applications for which the ability to test very large samples may be important.

4. EQUIPMENT DESCRIPTION

The equipment and recommended operating procedures were fully described immediately following construction in 1978. Since this documentation remains available (Chudobiak and Williams, 1976, 1977; Opsal, 1978; Eyre, 1984), only a brief description will be given here. Attention will be drawn to details of any modification made during the current phase of work and to differences in the design specifications and the actual operational performance of the equipment.

4.1 Pressure vessels

There are 10 (ten) creep cells in the facility. Each pressure vessel has a height of 1350 mm, an external diameter of 600 mm and a wall thickness of 150 mm. The internal piston for axial loading is sealed with "teflon" piston rings and has a diameter of about 430 mm. The axial load capacity is approximately 7 MN or 700 tonnes. A test cell is shown diagrammatically in Fig. 4a and a photograph of two pressure vessels forms Plate 4a.

The design specification indicates that the cells are capable of sustaining axial piston pressures and radial cell pressures of up to 50 MPa. In practice, the maximum pressure is limited by the hydraulic accumulator used to maintain pressure, and is about 40 MPa. Ideally a larger accumulator rated to 70 MPa is required to run more than a single cell.

4.2 Sample jackets

The cells are designed for samples of diameter 200 mm with a length of 400 mm. The original design specified precast urethane sample jackets to isolate the test samples from the hydraulic fluid used to provide the radial confining pressure. In practice, these jackets were found unsuitable and were replaced by "ecosil" (a more flexible plastic) jackets cast around the sample after the attachment of strain gauges.

4.3 Hydraulic control system

The radial and axial cell pressures are completely independent and can be computer controlled. Pressure transducers sense pressure changes and adjustments can be made by actuating solenoid valves. The design specifications require that pressures be maintained constant for extended periods to within ± 0.4 MPa. In practice, the precision is much greater. For manual operation using high precision gauges ± 0.02 MPa can be achieved and with computer control relying on the less precise transducers ± 0.3 MPa in the range 0-50 MPa.

The original unmodified hydraulic control system is shown in

Fig.4b. The most significant change to the hydraulic system was the elimination of the small hydraulic accumulators, which limited the load capacity to 35 MPa and acted as gas thermometers giving the hydraulic systems extreme temperature sensitivity. Plate 4b shows the main accumulator (extreme left), a small accumulator (right) and a set of typical taps, gauges, transducers and solenoid valves (centre).

A second important change was the addition of control valves to permit two-way pressure control in both cell and axial circuits. In the original design, no facilities for controlled "bleeding" of excess pressures was allowed. The modified hydraulic circuits are shown in Fig.4c.

4.4 Deformation monitoring system

During the evaluation vertical strains were monitored by resistance wire strain gauges cemented directly to the sample. Some concern over the adhesion of such gauges, especially vertical gauges subjected to compression, has arisen.

In the original design, vertical strain only was to be monitored by linear variable differential transformers (LVDT's), mounted above the pressure vessel as shown in Fig.4d. This system was unworkable for two reasons: the seals on the LVDT shafts were prone to leakage; and the hydraulic fluid in the cell tended to force the shaft out of the cell unless a significant opposing load was continuously applied.

A first modification was to attempt to measure vertical strains using potentiometers (pots) mounted inside the pressure vessels monitoring the displacement between the upper platen assembly and the piston skirt as shown in Fig.4e. Very large "seating" strains due to "slack" and strain in the piston-platen assembly were recorded using this system. The correspondence between strains from strain gauges bonded to the sample and strains from pots was very poor.

A second modification was attempted in which the pots measured sample strain directly by mounting them on steel bands around the jacketed sample as shown in Fig.4f. "Seating" strains were successfully avoided but the bands tended to restrict the diametral expansion of the sample ends if they were too tight, and slip if they were too loose. Correspondence between bonded strain gauges and pots was excellent when slippage was absent.

A third change involved the direct cementation of small, metal, circumferential shells to the sample surface at equally-spaced points near the ends. These shells were threaded so that a rod, to which the potentiometers were attached, could be firmly anchored. The ecosil sample jacket was cast around the shell attachments with the rod passing through the jacket as shown in Fig.4g.

This is the system currently in use for vertical strain monitoring. Agreement between pots and strain gauges is good. A further modification involving attachment through the jacket to the platen face is under consideration.

Horizontal strains are monitored by resistance wire strain gauges. Attempts to develop "girth" monitors using spring loaded bands and resistance wire wraps have made little progress to date. The estimation of volumetric strains from cell-oil volume changes has yet to be perfected and awaits the refurbishing of the solenoid valves which delayed the development and testing of control software.

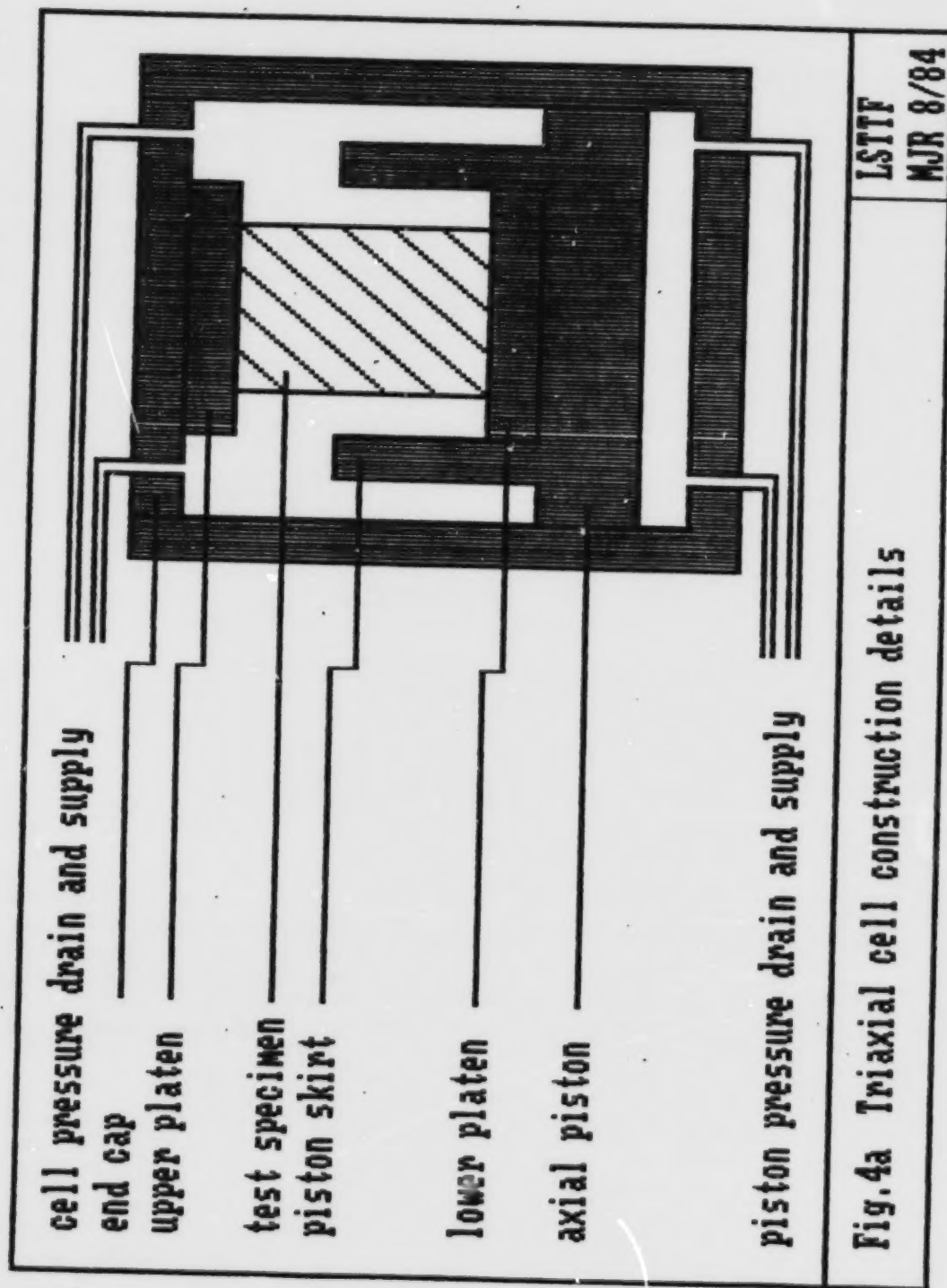
4.5 Computer logging and control systems

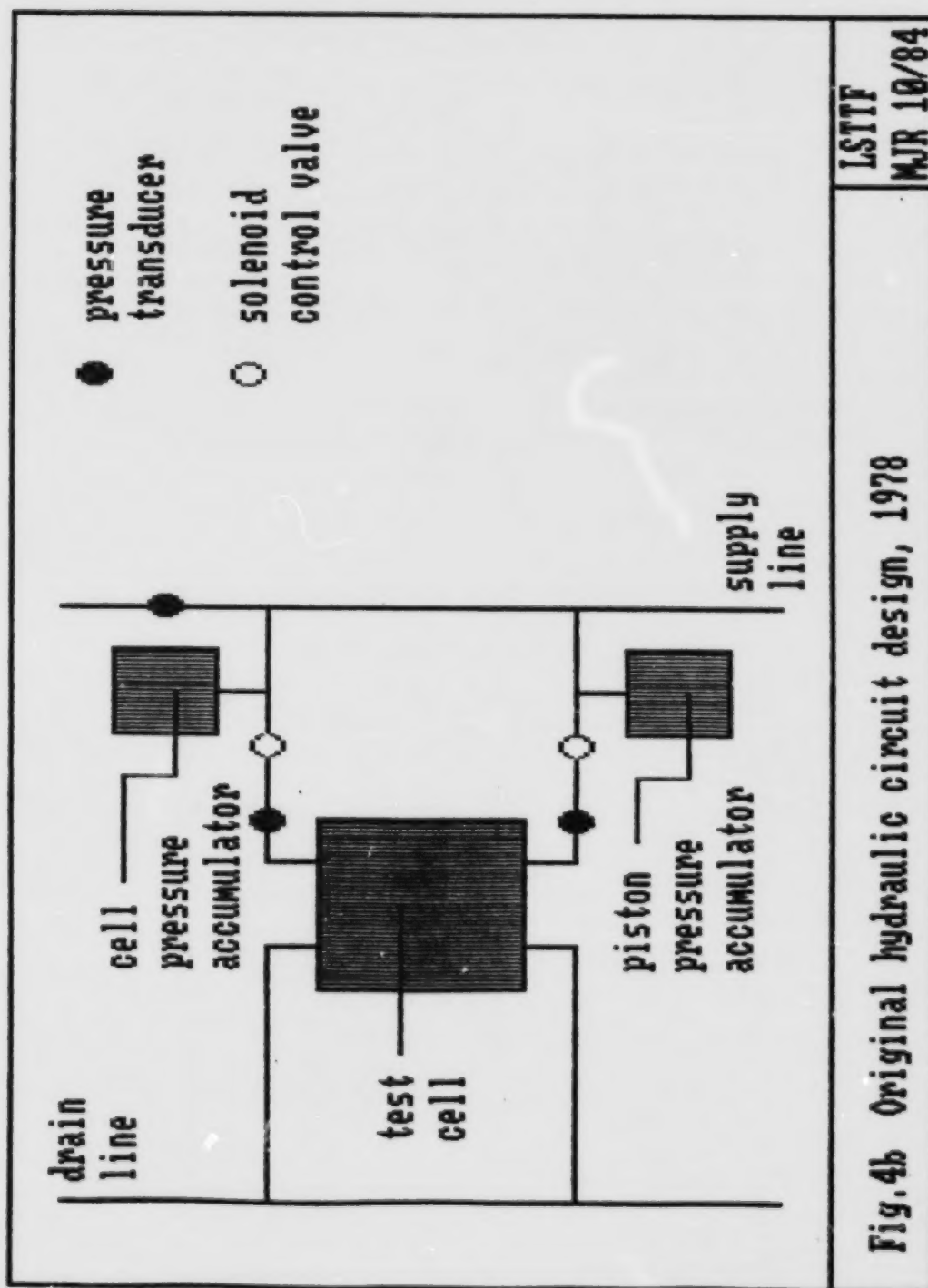
The original electronics installed prior to 1978 are used for signal conditioning, though the original Hewlett-Packard HP 9825A computer and Neff controller/logger have been replaced.

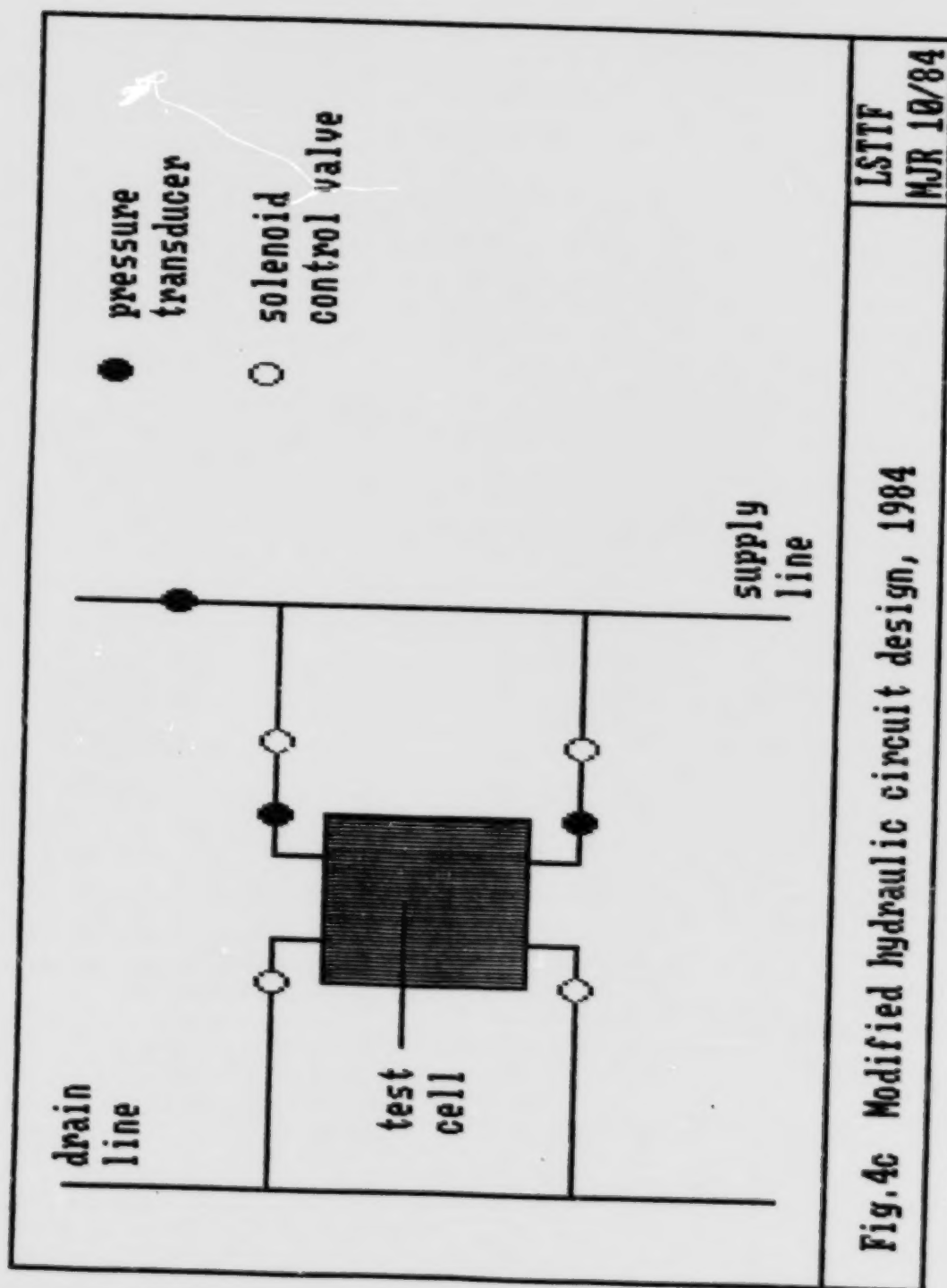
Initially it was intended to use an IBM-PC computer (or compatible) with an on-board logger controller card for the laboratory. Although software has been developed and all individual logging and control operations tested, a Fluke serial logger attached to an Hewlett-Packard HP85 computer has collected most of the logged data.

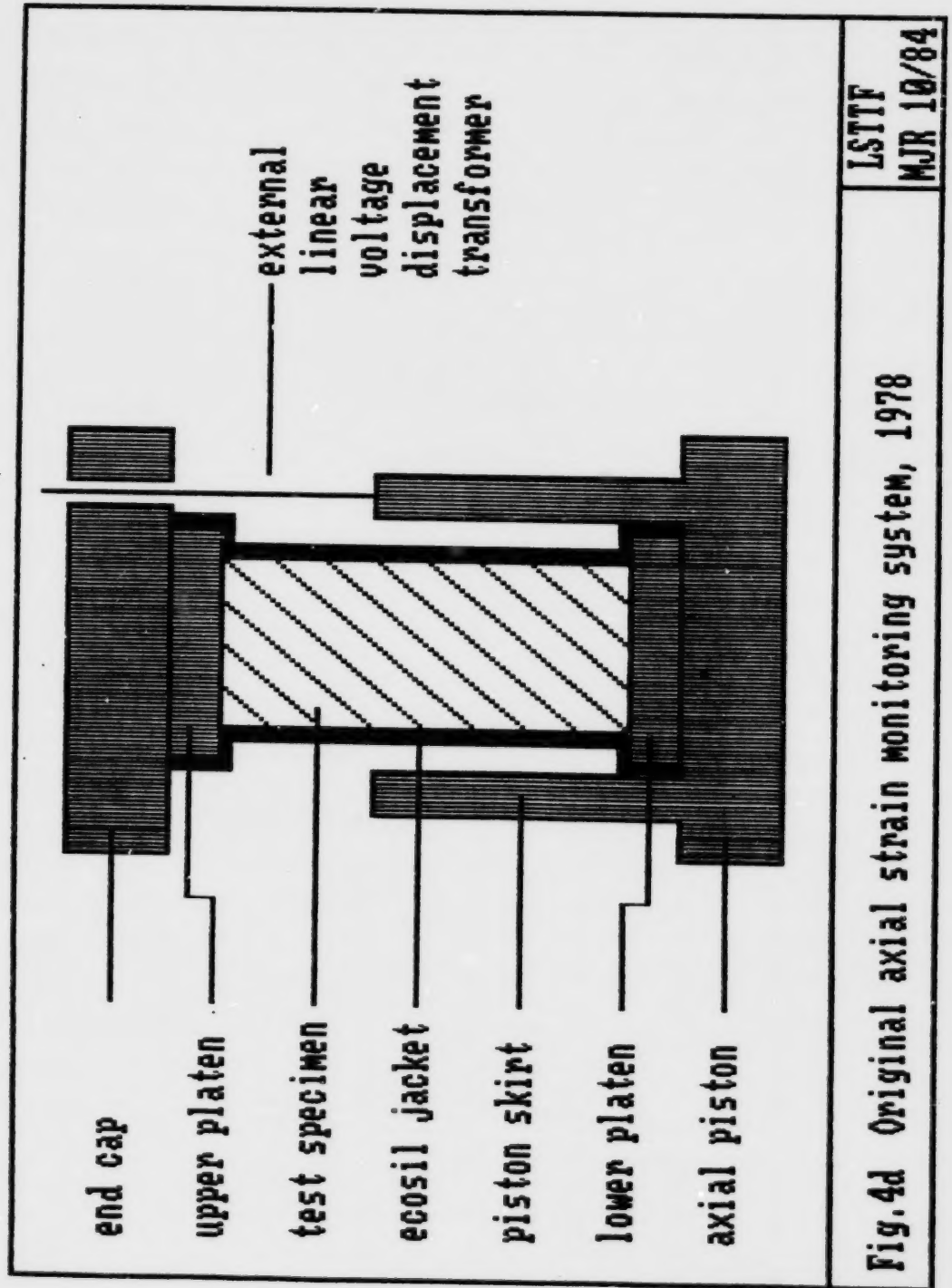
This situation arose largely because the IBM-PC could not be used for development purposes if it was committed to routine logging. Having tested the PC software on an experimental basis, the solenoid valves, which are at the heart of the control system, began to fail in service due to deterioration of "o"-ring seals. Thus, although every aspect of logging and control systems have been tested, a fully controlled test with no manual intervention has yet to take place.

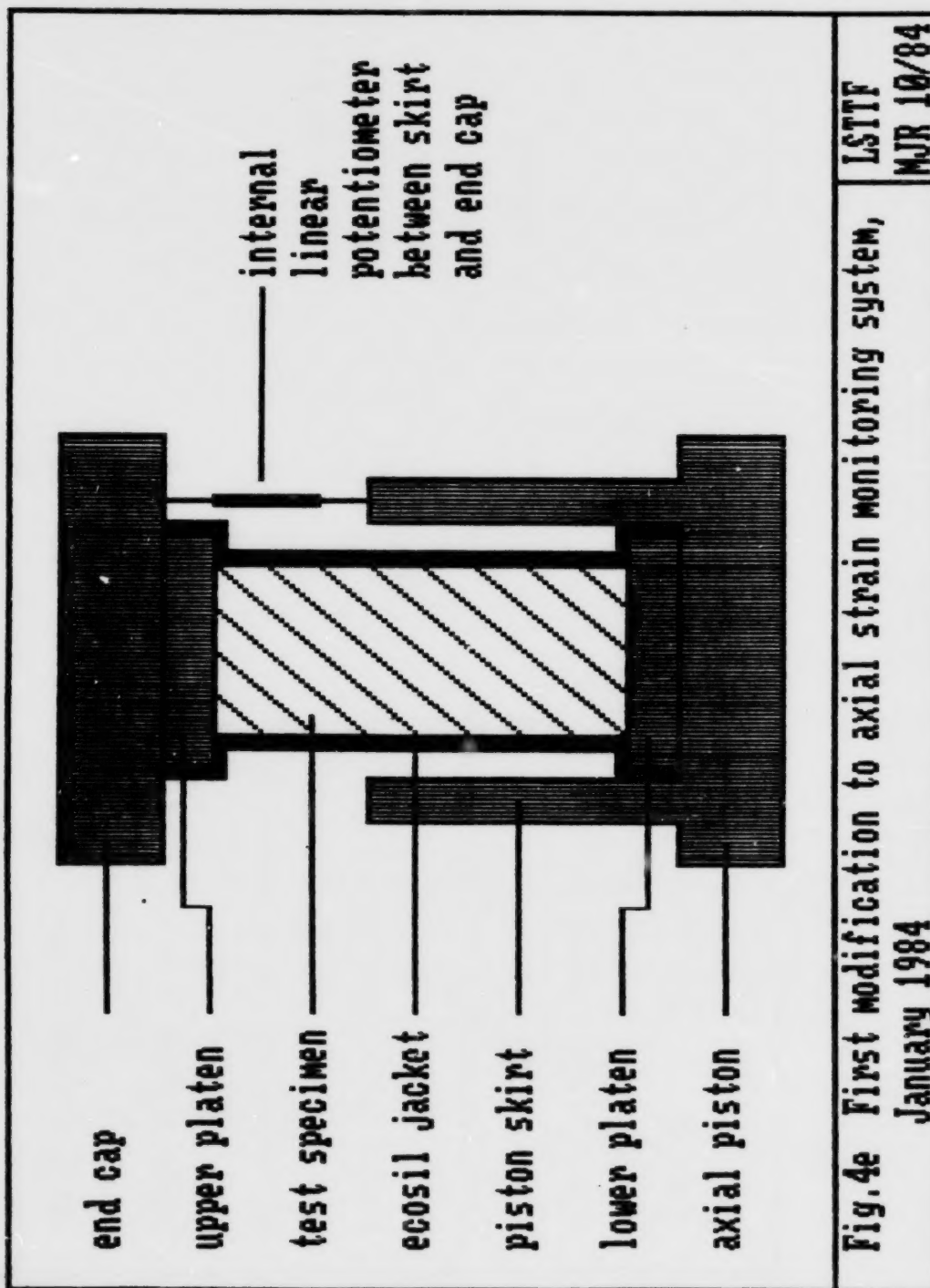
However, the data acquisition and control system has been fully tested on the 100 mm dia. sample GELUS test equipment using transducers, potentiometers and solenoid valves similar to those utilised in the LSTTF. Only minor modifications in the hardware interface (different signal conditioners) are necessary to transfer the D-A (digital to analogue) system between labs, the software being identical.

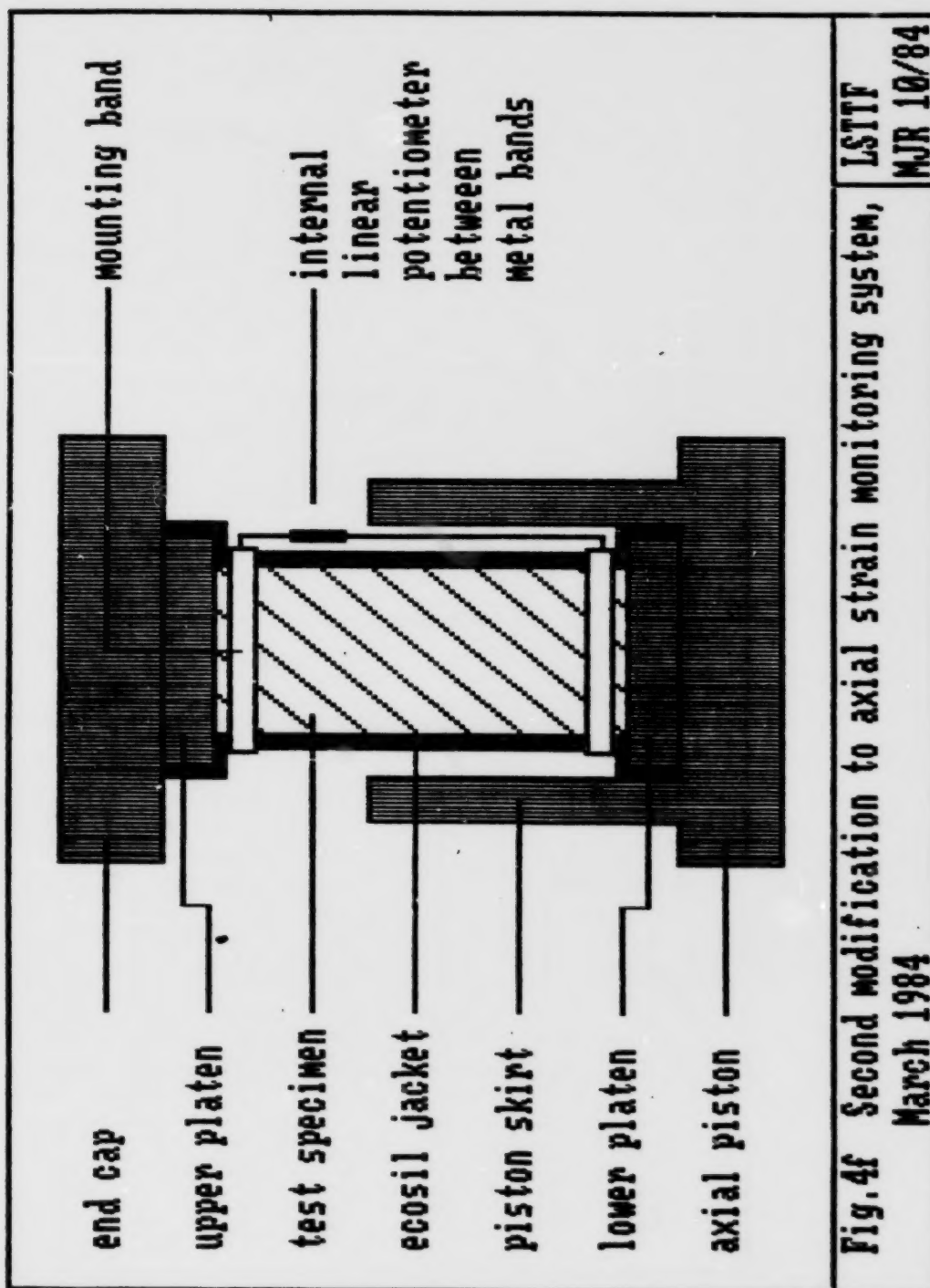












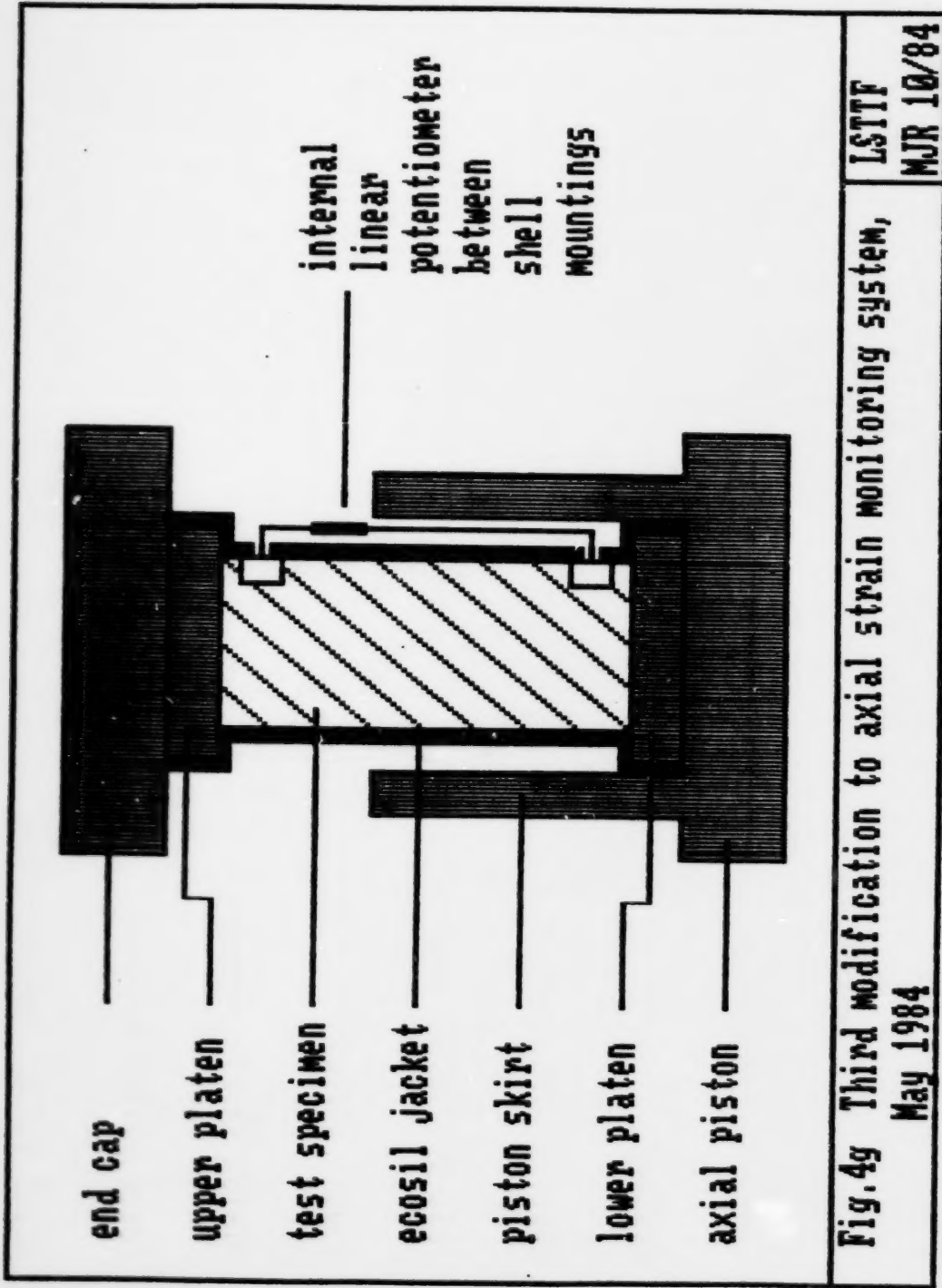


Fig.4g Third modification to axial strain monitoring system,
May 1984
LSTTF
MJR 10/84

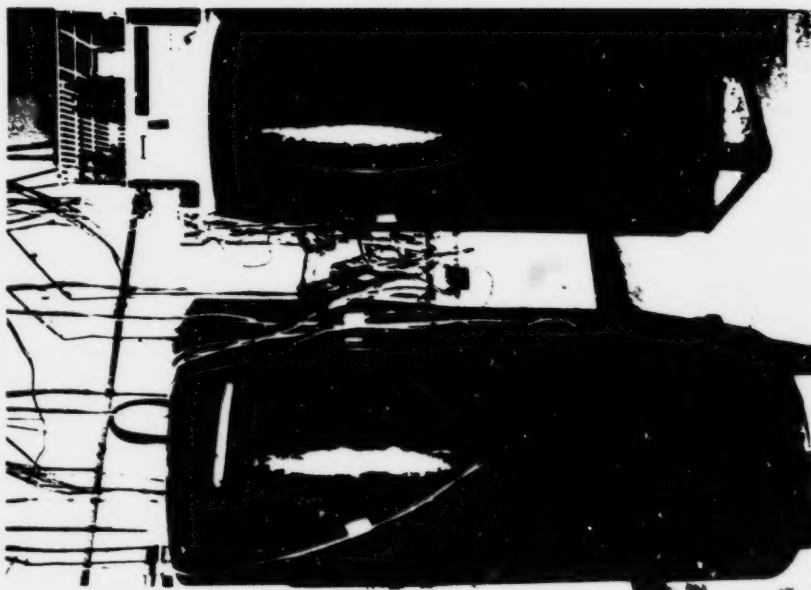


Plate 4a: Triaxial pressure vessel.

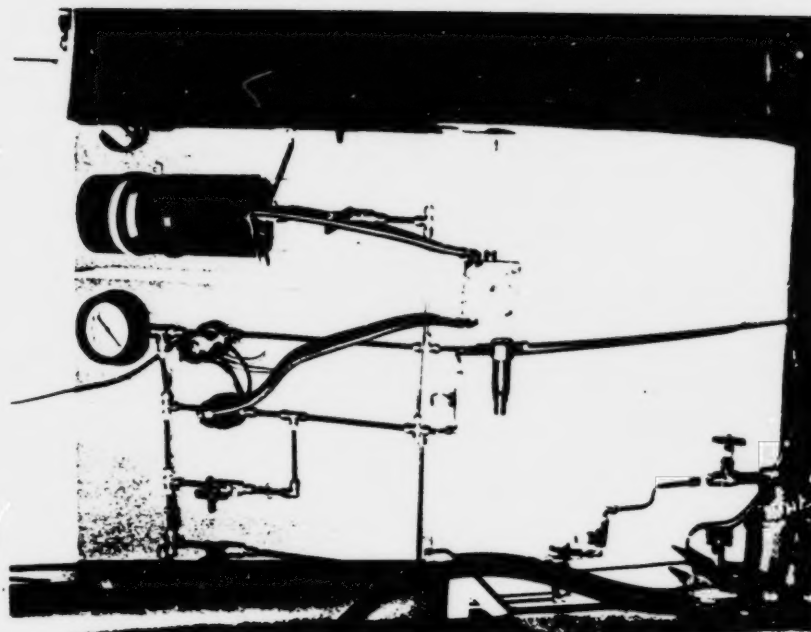


Plate 4b: Hydraulic accumulator and controls.



5. TEST SPECIMENS

5.1 Aluminium test cylinder

The aluminium test-piece comprised a 250 mm diameter x 300 mm cylinder which was instrumented with 6 x 50 mm length resistance wire strain gauges (3 vertical, 2 horizontal) placed symmetrically on the cylinder surface at about the approximate mid-point in the axial direction. The test cylinder was tested for elastic response by loading in the 400 tonne Tinius-Olsen compression machine at GELUS. The derived elastic parameters (Young's modulus and Poisson's ratio) agreed very closely with the published values for the material and an almost perfectly linear stress-strain curve with virtually no hysteresis was obtained. Plate 5a shows the aluminium test cylinder with attached strain gauges.

The response of the aluminium test cylinder was used to calibrate the creep laboratory hydraulic cells where it was used as a load cell. Attempts to purchase or construct a load cell to be used "in-line" with "soft" rock cores were abandoned for three reasons.

- (a) The time involved in designing and building a "one-of" cell with appropriate capacity, low vertical height and minimal hysteresis was not available.
- (b) The creep cells were not designed to use a load cell and incorporation of such a cell would require either a reduction in the 2:1 height:diameter ratio for test specimens or complete rebuilding of one of the platens.
- (c) The aluminium test cylinder proved a very adequate substitute in the early tests and provided confidence that the axial and radial hydraulic pressures measured in the creep cells were reliable indicators of load and that frictional losses in the hydraulic pistons were acceptably small.

The data for the aluminium cylinder response to known loads and the calibration data for uniaxial loading in the creep cells are given in section 6 which is concerned with calibration tests.

5.2 Evaporite test specimens

5.2.1 Sampling

Evaporite test specimens were obtained with a 200 mm internal diameter carbide "toothed" coring bit which proved an excellent cutting tool with almost 100% recovery. Most broken cores were attributed to pre-existing sub-horizontal discontinuities. A plywood "collar" with a thickness of about 100 mm was affixed to the face to be sampled to act as a guide to "start-off" the bit.

Samples were obtained with the co-operation of PCS and Cominco who provided drilling rigs and drillers at no cost to the project. Both companies also contributed valuable advice on sampling procedures.

A total of 11 cores were obtained between November 1983 and June 1984 but because of time limitations and the considerable expense involved in specimen preparation, instrumentation and installation in the test cell, only 7 different cores were used in the tests. Three out of the 11 cores were fractured and therefore could not be used.

5.2.2 Preparation

The rough cores were wrapped in heavy duty plastic sheeting with one end exposed and cut with a 900 mm diameter diamond saw blade. Water was used as a cutting lubricant on the "offcut-side" of the blade only. Early preparation attempts with kerosene and brine as lubricants were abandoned since little contamination occurred with the "one-sided" fresh water lubrication. Both recirculation and corrosion were problems with the other fluids. It is possible to use recirculated brine successfully but after each cutting session the saw, recirculating pump and pipework must be extensively flushed with fresh water.

The sawn faces obtained in this way were close to (but not exactly) parallel. Grinding to give perfectly parallel faces would be desirable during material property testing, but for the series of tests designed to evaluate the test rig, non parallel faces were used in an attempt to induce assymetric loads and check the effectiveness of the hollow-ground self levelling platens. The most parallel faced cores were used for the later series of tests which were oriented more towards the determination of evaporite properties.

With practice, sawn ends parallel to within less than 1 degree could be readily obtained. Manual grinding of core ends to give a smoother surface and the use of lubricants between core and platen are the subject of on-going experimentation. Because of the high cost of each individual test, it is not possible to quickly test a large number of methods. However, objective measurements of the degree to which ends are parallel to one another and normal to the core axis, together with core end roughness statistics are being collected.

The ISRM committee on laboratory tests recommend ends flat to 0.02 mm, axis perpendicular to 0.001 radians, height to diameter ratio of 2.5 to 3 and diameter no less than 10 times the largest grain diameter. These standards for "end" preparation have not been met but could be approached without major investment in new equipment. The inevitable delays in modifying lathes and grinders to take the large samples were not deemed necessary for the

present evaluation.

5.2.3 Storage

The early cores obtained prior to October 1983 were not treated very carefully. They were trimmed (ends sawn) then coated with an impermeable clear plastic "paint" to minimise evaporative moisture loss and/or hydration by atmospheric moisture. They were then stored (core axis vertical) in the laboratory at an ambient temperature of 25 degrees Celsius. Although the relative humidity was not controlled it is known to be very low. Some of the samples may have suffered desiccation and/or hydration prior to testing.

These samples were used in the equipment evaluation phase of testing and, with the exception of some cyclic stress-strain curves obtained immediately (within 10 days) after sampling, were not used to determine material properties.

For the later triaxial load test series, fresh cores were obtained in May/June 1984. With only one cell in operation, satisfactory core storage is a major problem since a single sample can occupy the cell for as long as 60 days. It is recommended that the cores be either instrumented and consolidated immediately or wrapped in plastic sheeting to minimise moisture loss and/or hydration. Samples should be stored for as short a time as possible prior to testing or consolidation.

5.2.4 Instrumentation

In early tests, the evaporite cores were instrumented with 6 resistance-wire strain gauges (3 vertical and 3 horizontal each 100 mm long). Adhesion to the rock surface was found to be good for gauges in tension and the gauge response is excellent up to 5% strain. Some adhesion problems were suspected for the vertical gauges in compression since potentiometer measurements of strain are consistently higher than those from bonded gauges. This problem was not isolated until reliable attachments for potentiometers on the sample were developed. In later tests the vertical gauges were eliminated. These problems are discussed further in the later text.

When pots alone were used for vertical strain, up to five horizontal strain gauges were employed. This arrangement gives a virtually uninterrupted girth around the core and extends the maximum diametral strain that can be reliably measured before all gauges are ruptured. Following failure of all "girth" gauges, at vertical strains in excess of 20% under normal circumstances, reasonable estimates of diametral strain may be obtained by direct quantitative estimation of the volumetric strain, based on the net change in the volume of fluid in the cell. Such complete gauge failure was encountered only once, when the gauges had survived 90 days of hydrostatic consolidation, although

individual gauges have often failed due to "pop-out" of large crystals.

5.2.5 Jacketing

The original jackets intended for use in the creep cell were of precast "adiaprene", a very tough urethane plastic. Tests on the jackets alone (no specimen inside) indicated that a considerable "stiffness" was involved and that the jackets were likely to significantly enhance the strength of test cores.

A second disadvantage was that the precast jackets required the cores to be precisely 400 mm diameter x 800 mm long which placed severe, and largely unnecessary, constraints on the sample acquisition and preparation procedures.

A third difficulty was encountered in inserting the instrumented core into the jacket without damage to the electrical connections to the strain gauges.

These problems were overcome by replacing the rigid, precast urethane jackets with more flexible "ecosil" jackets cast around the evaporite cores after instrumentation has been attached. This procedure is identical to that used successfully for many years at GELUS in testing cores with diameters up to 100 mm.

"Ecosil" is a commercially available, flexible, low-shrinkage two-component (liquid and hardening agent) plastic.

5.2.6 Core Description

Some typical core slices from the PCS mines at Cory and Rocanville and the Cominco mine at Vanscoy were subjected to chemical, mineralogical and microscopic grain-size analyses.

Since relatively few core slices were analysed, there are no clearly defined differences between the three localities, indeed there is almost as much difference between the 3 Cory slices as there is between the Cory and Vanscoy sites. Even within a single 200 mm diameter x 400 mm core, large differences between slices can be found.

The descriptions and analyses do no more than indicate the range of compositional variation in the "potash" formations. Table 5a identifies the cores used in the laboratory tests. Plate 5b shows the Rocanville core R1 with attached strain gauges.

Table 5a : Identification of evaporite test specimens.

Specimen I.D.	Locality (mine)	Date obtained
R1	PCS Rocanville	October 1983
C1	PCS Cory	October 1983
C2	PCS Cory	October 1983
C3	PCS Cory	October 1983
V1	Cominco Vanscoy	May 1984
C4	PCS Cory	June 1984
C5	PCS Cory	June 1984

Core R1 was obtained by drilling vertically upward into the back of an opening. The core displays sub-horizontal banding and is predominantly composed of halite. The banding is demonstrated by both crystal-size and compositional variations. Halite crystals have dimensions of up to 50 mm, whereas those of sylvite rarely exceed 20 mm.

Cores C1-C5 were obtained by drilling horizontally into the wall of an opening. Compositional and crystal-size banding is apparent parallel to the long axes of the cores as illustrated in Plate 5c. Halite crystal dimensions range up to 30mm and sylvite crystals up to 15 mm.

Core V1 was obtained by drilling vertically downward into the floor of an opening. Subhorizontal banding is strongly present and clay-rich bands can be detected. Maximum chloride crystal dimensions are comparable to those observed in the Cory cores C1-C5.

Thin "offcut" slices from each core were subjected to X-ray diffraction and chemical analysis. The Cory (C1-C5) analyses are probably fairly representative of the core as a whole, while the Vanscoy (V1) and Rocanville (R1) analyses are much less representative owing to the orientation of the banding.

In Table 5b, estimates are made of the mineralogical composition based on both XRD and chemical analyses. Concentrations of less than 1% are recorded as traces (Tr). Insolubles refers to distilled water digestion and includes clay minerals, quartz and some carbonates which are shown up by XRD.

Table 5b : Approximate percentage of minerals in test specimens

I.D.	Insolubles	Carnalite	Anhydrite	Halite	Sylvite
R1	2	2	Tr	85	11
C1	2	1	-	40	57
C2	6	2	Tr	25	67
C3	8	1	Tr	42	49
V1	7	1	Tr	50	42
C4	6	-	Tr	63	31
C5	6	-	Tr	67	27

5.2.7 Costs

The material costs involved in instrumenting and jacketing a single 200 mm diameter core are roughly \$500 (1984 prices). The preparation including cutting and facing involves at least 6 man-hours of skilled technician time (say \$300). Considerable additional time is involved in installing the sample in the triaxial cell and in making the necessary hydraulic and electrical connections. It is conservatively estimated that the total investment in a single specimen before testing is \$2000 (1984 prices). During the commissioning phase for the equipment and instrumentation, these costs are increased by a factor of 3 or 4 since the test procedure, instrumentation and even the equipment itself was modified in some way as a result of lessons learned from the previous test.

Some of the cost is attributable to the size of the specimens and the weight of the components of the pressure cells which are assembled and disassembled with the aid of a crane. However, the costs per unit volume of sample tested are comparable (and probably somewhat lower) than those for smaller samples. A 100 mm diameter core, for example, can be prepared at only one half to one third of these costs.

The total cost of testing on a per sample basis is at least \$5000 for a relatively simple computer controlled test without elaborate temperature control.

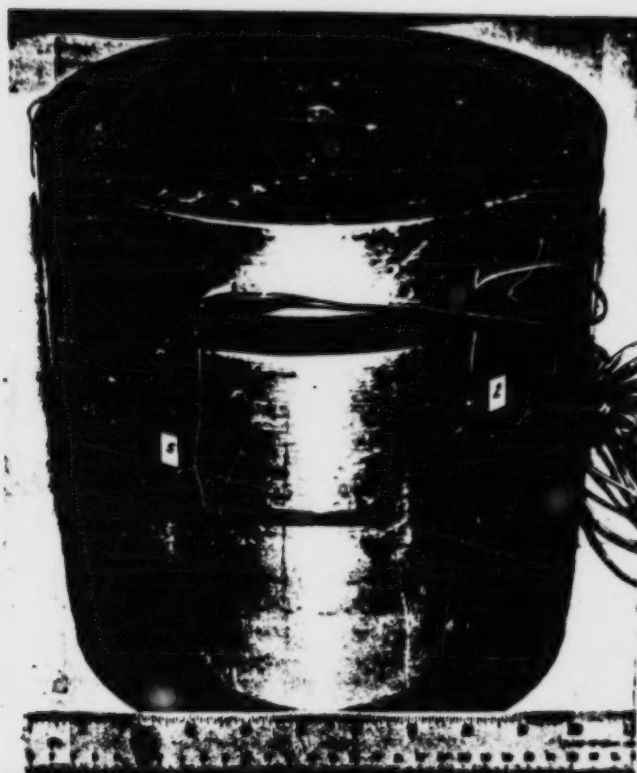


Plate 5a: Aluminum test cylinder with strain gauges.



Plate 5b: Potash core R1 with strain gauges.

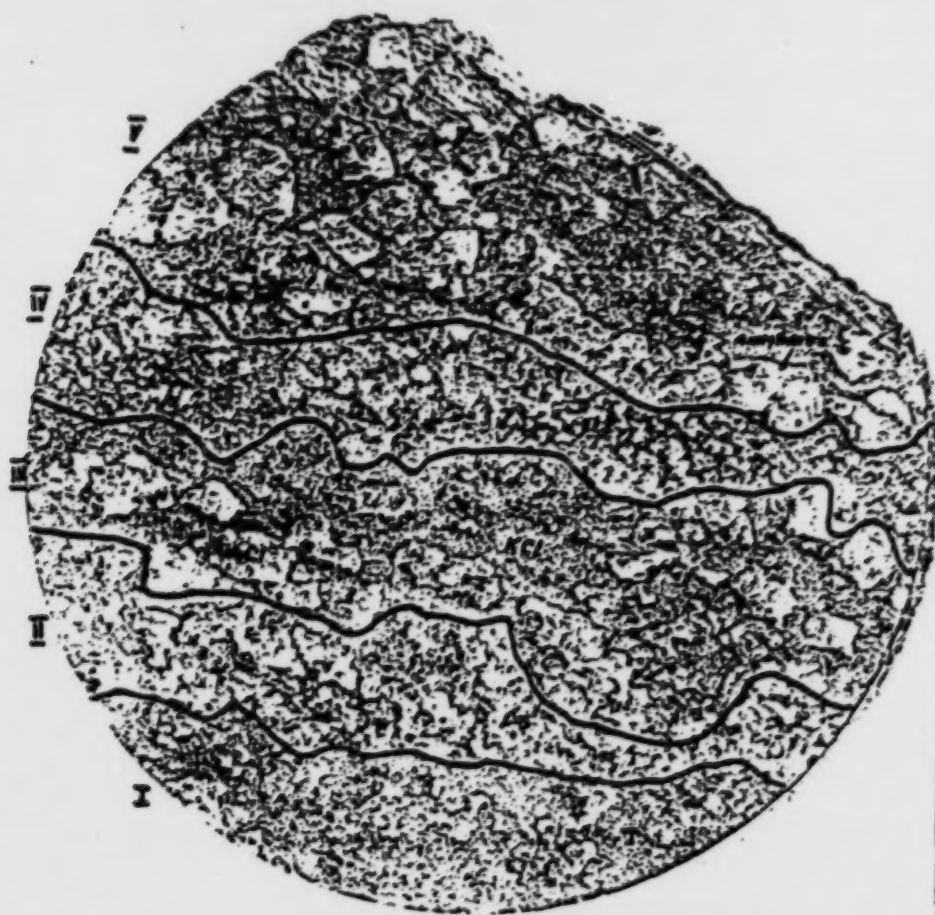


Plate 5c : Banded structure of evaporite cores.

6. CALIBRATION TESTS

A number of uniaxial tests were carried out on the 400 tonne capacity Tinius-Olsen compression machine at GELUS, to determine the load-deformation behaviour of both the aluminium test cylinder and the evaporite test specimen R1.

Similar tests were repeated in the LSTTF to check that the axial piston loads were fully transferred to the test specimen.

6.1 Aluminium cylinder

The aluminium cylinder was instrumented with 3 vertical and 2 horizontal resistance-wire strain gauges. Vertical and horizontal gauge response averages are plotted on stress-strain curves.

6.1.1 Calibration Test #1 : aluminium cylinder : 12 July 1983

The aluminium cylinder was uniaxially loaded in the Tinius-Olsen (GELUS) compression machine to a maximum axial stress of 21.4 MPa in 25 approximately equal increments at approximately 2 minute intervals (0.43 MPa/min). Incremental unloading followed immediately. The resulting stress-strain curves are shown in the composite plot Fig.6a as solid lines. Hysteresis is minimal and the gradient yields a value of 73 GPa for the elastic modulus. Poisson's ratio is 0.38. These values are in close agreement with the expected values of 72 GPa and 0.33.

6.1.2 Calibration Test #2 : aluminium cylinder : 20 Jan. 1984

The aluminium cylinder was uniaxially loaded in the LSTTF cell to a maximum axial stress of about 22 MPa in 11 equal increments at 5 minute time intervals (0.40 MPa/min). Incremental unloading using a similar schedule followed immediately. The stress-strain curves are shown for axial and radial strains as dashed lines in Fig. 6a. The stress-strain curves for the two laboratories (GELUS and LSTTF) show excellent agreement. The elastic modulus for test #2 was 70 GPa and Poissons ratio 0.32.

6.1.3 Calibration Test #3 : aluminium cylinder : 21-22 Dec. 1983

Test #3 was carried out to determine the precise value of axial pressure required to initiate piston movement. Measurements of the dynamic friction were also made for various displacement rates up to .066 mm/sec. Fig.6b shows the axial pressure necessary to sustain movement for various constant displacement rates.

The pressure increment to initiate movement is a little higher than the dynamic intercept value on Fig.6b.

6.2 Evaporite test specimen R1

The evaporite test specimen R1 was instrumented with 3 vertical and 2 horizontal resistance-wire strain gauges. Vertical strains were also recorded with dial gauges in the GELUS experiments and pots in the LSTTF. Stress-strain curves are plotted using averaged gauge readings.

6.2.1 Calibration Test #4 : evaporite specimen R1 : 19-20 Sept. 1983

The evaporite core was repeatedly uniaxially loaded in the Tinius-Olsen compression machine over the range from zero to about 5 MPa in increments of 0.6 MPa at time intervals of 5 minutes (0.13 MPa/min). The resulting stress-strain responses for axial and diametral strain are shown in Fig.6c as solid lines.

6.2.2 Calibration Test #5 : evaporite specimen R1 : 17 Mar. 1984

Because of the long delay in commissioning the LSTTF cell, core R1 was exposed to laboratory atmosphere for 6 months under a small axial stress (about 3 KPa). For this reason a second calibration test was carried out.

The evaporite core was repeatedly uniaxially loaded in the Tinius-Olsen compression machine over the range from zero to about 5 MPa in increments of 0.6 MPa at time intervals of 5 minutes (0.13 MPa/min). The resulting stress-strain responses for axial and diametral strain are shown in Fig.6c as dashed lines. Comparison with test #4 suggests that the apparent modulus for similar strain rates has been reduced considerably. This "stiffening" effect is thought to be largely a function of desiccation rather than creep since the sealing of the core was incomplete during the long period of storage between tests.

6.2.3 Calibration Test #6 : evaporite specimen R1 : 3 Apr. 1984

The evaporite core R1 was subjected to a single uniaxial load-unload cycle in the LSTTF cell. The load was incremented by about 0.3 MPa at 3 minute intervals (0.10 MPa/min) to a peak level of about 5 MPa. The resulting stress-strain responses for axial and diametral strain are shown in Fig.6c as dashed lines.

Tests #5 and #6 show reasonable correspondence indicating the comparability of the GELUS and LSTTF loading systems.

6.3 Conclusions from calibration tests.

The correspondence of tests #1 and #2, and tests #5 and #6, together with the direct measurements in test #3, gave some confidence that the LSTTF cell transfers the axial load to the test specimen without significant losses in friction.

Tests #4, #5 and #6 show that dial gauge and potentiometer strains based on the total length change in the sample are significantly and consistently greater than those taken from strain gauges bonded to the test specimens. For the aluminium sample, dial gauge readings (not plotted) and strain gauges were consistent. It was provisionally concluded that a gauge-adhesion problem might exist leading to an underestimate of strain. The conclusion could not be firmly drawn because slippage of the LSTTF potentiometer mounts and "slack" in the piston assembly, leading to an overestimate of strain could not be ruled out. However, the dial gauge measurements in tests #4 and #5 are thought to be accurate.

Test #3 indicates that the magnitude of the static force, necessary to overcome piston friction, is equivalent to an axial pressure increment of no more than 0.08 MPa. The dynamic resistance increases with strain rate to perhaps four times this value at the maximum operational rate of strain.

Although 0.08 MPa is insignificant for tests on rocks (even evaporites), 80 KPa is not insignificant in terms of soil strengths and piston friction may have to be investigated further if soils applications are pursued. At low strain-rates it has been confirmed that the sensitivity of the loading system is very high and that once the initial 80 KPa has been applied incremental loads of less than 1 KPa can be accurately transferred to the sample.

FIG. 6a CALIBRATION TEST #1 & #2:
stress-strain load-unload cycle
curves for aluminum cylinder.

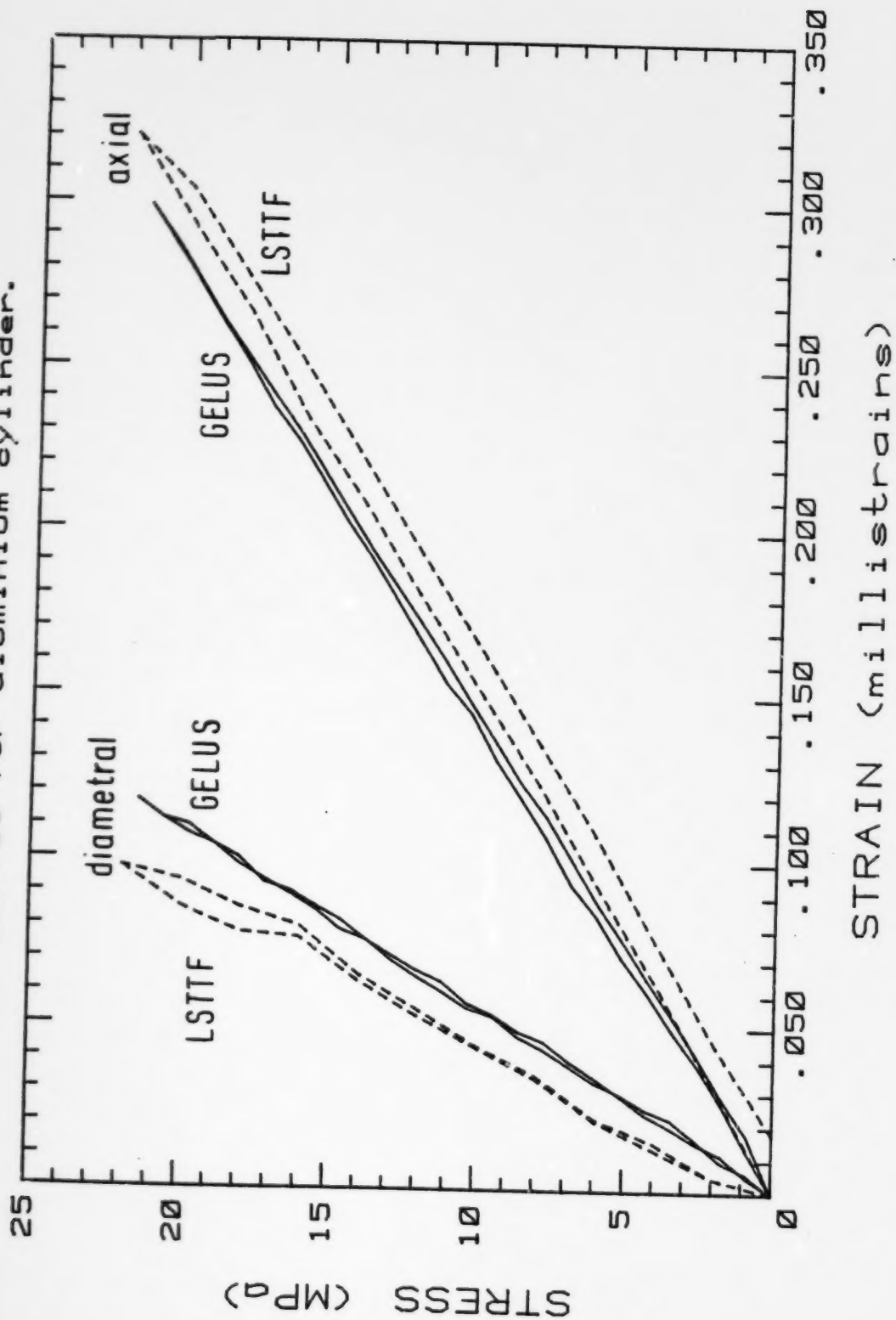


FIG. 6b CALIBRATION TEST #3:
stress-strain-rate curve for dynamic
friction of axial piston in LSTTF cell.

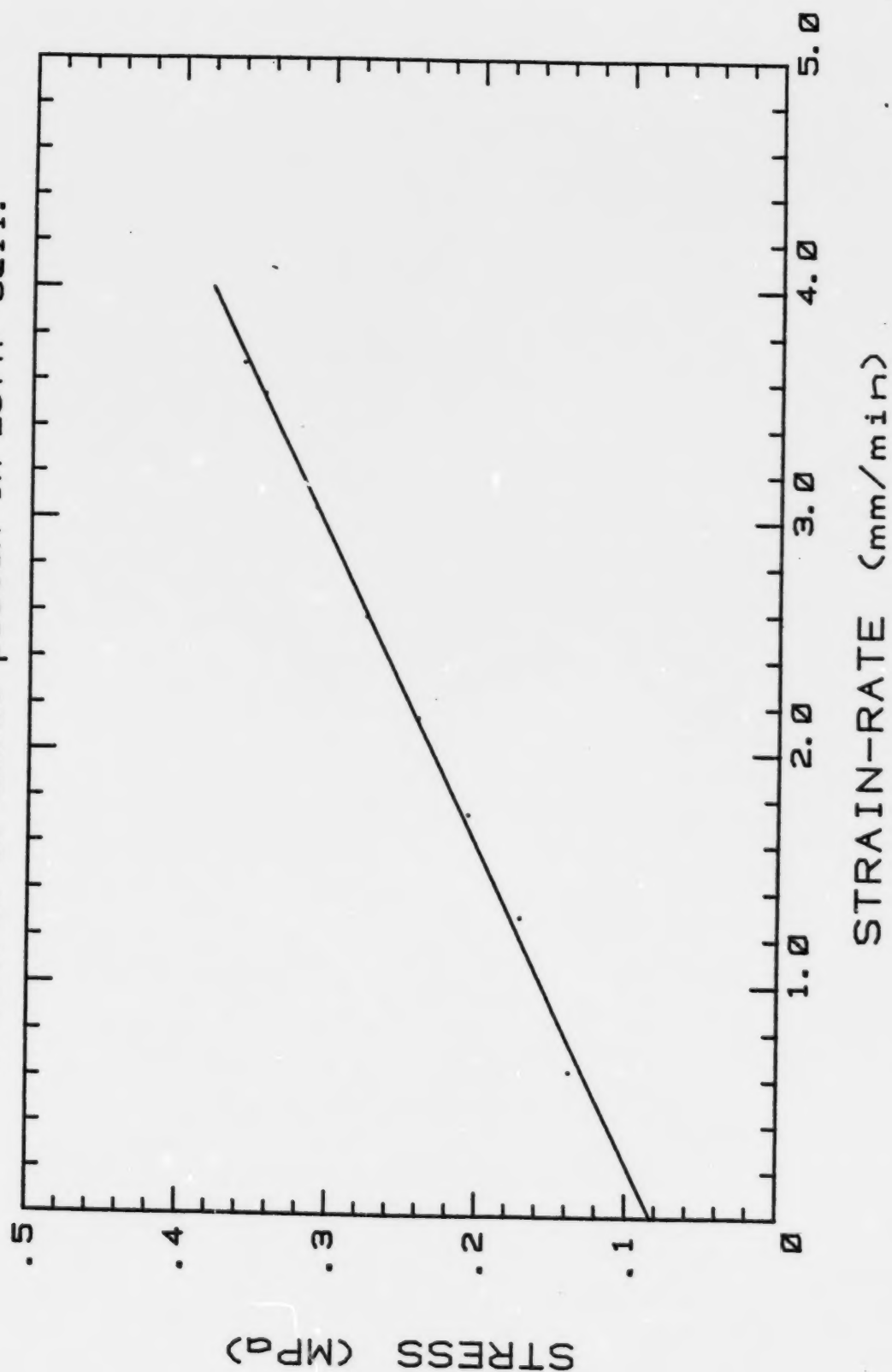
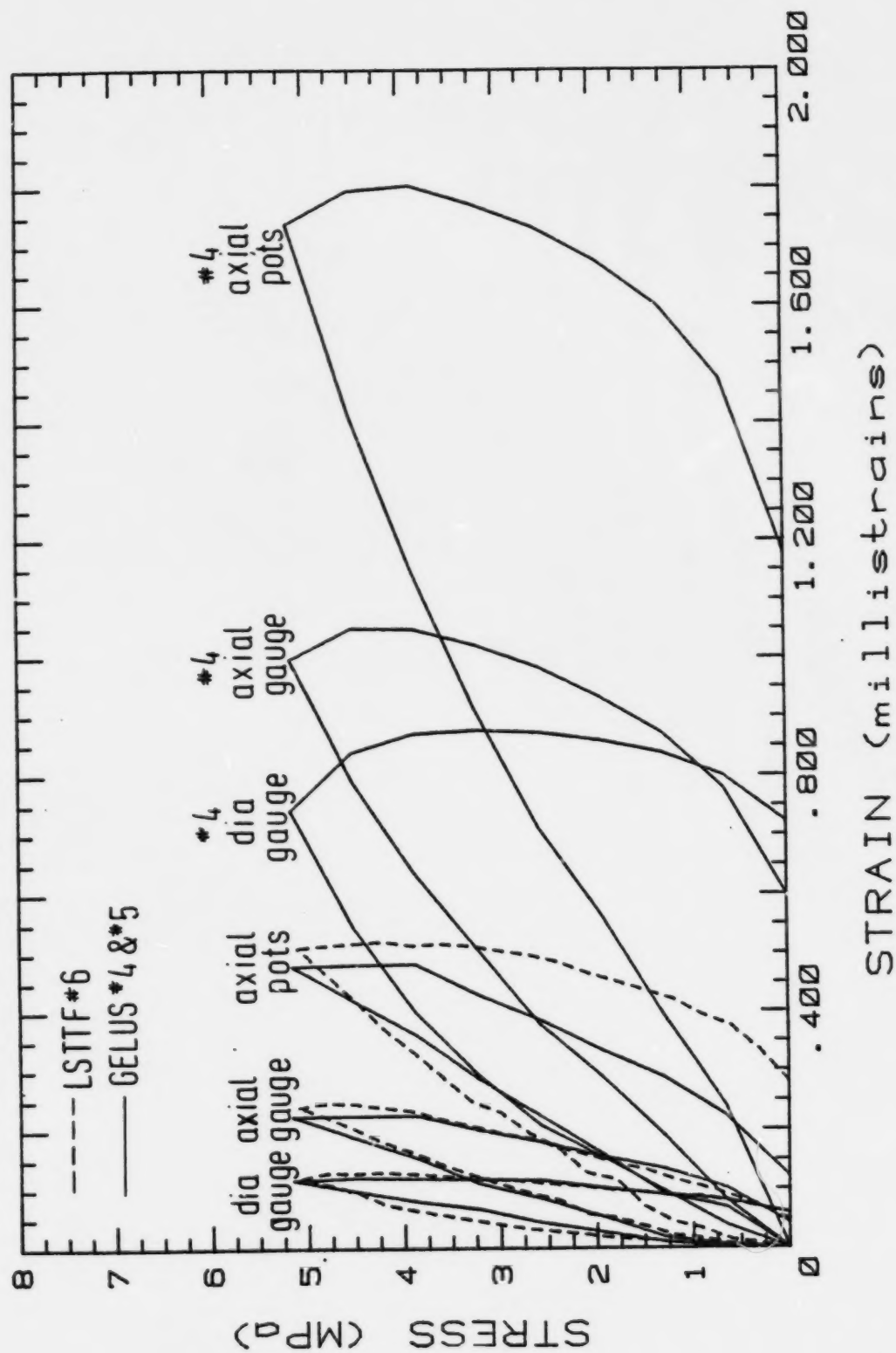


FIG. 6c CALIBRATION TEST #4 - #6:
stress-strain load-unload cycle
curves for evaporite test specimen R1.



7. PRESSURE TESTS

A series of pressure tests were devised to discover and rectify any significant leaks in the pressure vessel and hydraulic "plumbing" systems. Since slow pressure loss is inevitable, attempts were made to determine the rate of pressure loss if manual or computer controlled adjustments were not made. The frequency and magnitude of pressure adjustments necessary to maintain constant load on a test specimen were logged. The pressure tests employed the aluminium test cylinder acting as a "load cell". All figures show axial pressure as a solid line and cell pressure (i.e. radial pressure) as a dashed line.

7.1 Pressure test series #1

This initial series of pressure tests were carried out with the original hydraulic circuits (Fig.4b) which were subsequently found to be both more temperature sensitive and leak-prone than the modified configuration (Fig.4d).

7.1.1 Pressure test #1.1, 20-21 Jan. 1984

The axial piston pressure and radial cell pressure were raised to about 7.5 MPa and monitored for a period of about 19 hours. Fig.7a shows that the pressure losses amount to over 20% over this period but occurred at a decreasing rate as time passed.

7.1.2 Pressure test #1.2, 21-22 Jan. 1984

The axial and cell pressures were raised to about 10 MPa and monitored for a further 21 hour period. Fig.7a shows that pressure losses were similar in pattern with those observed in test #1.1. but the magnitude of losses was reduced to less than 10%.

7.1.3 Pressure test #1.3, 22-23 Jan. 1984

All valves and fittings were checked for pressure tightness and the test at about 10 MPa was repeated with no significant pressure loss over a period of 21 hours as demonstrated in Fig.7a. Note that the pressure was not reduced between tests #1.2 and #1.3, it was merely adjusted back to about 10 MPa.

7.1.4 Pressure test #1.4, 23 Jan. 1984

The form of the pressure loss against time curves for tests #1.1 to #1.3 suggested that the system was relatively leak-free but that early pressure losses were experienced due to "creep" in the

"plumbing" system.

In test #1.4, the axial pressure alone (no radial pressure) was raised in increments of 0.7 MPa and "creep" allowed to take place for 10 mins between increments. The final axial pressure of approximately 7.5 MPa was sustained for 2.5 hours prior to incremental unloading at 10 minute intervals.

Each 10 minute "creep" interval during the load cycle resulted in a pressure loss of between 1% and 2%. The 2.5 hours at peak pressure involved a drop of about 6%. On unloading, pressure rises occurred during the 10 minute periods between increments. The data are plotted in Fig.7b.

The immediate pressure drops and increases associated with incremental changes in pressure in tests #1.4 were traced to the thermal sensitivity of the small accumulators used to sustain pressures.

7.1.5 Pressure test #1.5, 23-24 Jan. 1984

This test is a uniaxial pressure test similar to test #1.4 with increments of about 1.4 MPa to a maximum axial piston pressure of 10 MPa. The axial pressure was raised incrementally allowing time for thermal settling in order to avoid the effects demonstrated in test #1.4. The results show a pressure loss of about 5% over 16 hours as illustrated by Fig.7c.

7.1.6 Pressure test #1.6, 24-25 Jan. 1984

Test #1.6 was an attempt to sustain a radial pressure of 10 MPa and an axial piston pressure of 20 MPa. The cell and axial pressures were raised incrementally allowing time for thermal settling of the small accumulators. The test results are plotted in Fig.7c and show small pressure losses of about 2% over 15 hours.

7.1.7 Pressure test #1.7, 25-26 Jan. 1984

Test #1.7 was an attempt to sustain a radial pressure of 20 MPa and an axial piston pressure of 30 MPa. The procedure was identical to that for test #1.6. The test results in Fig.7c show a small pressure loss (<2%) over 17.5 hours.

7.1.8 Pressure test #1.8, 26-27 Jan. 1984

Test #1.8 was an attempt to sustain a radial pressure of 30 MPa and an axial piston pressure of 40 MPa. The procedure was identical to that for test #1.6. The test results in Fig.7c show a small pressure loss (<2%) over 17 hours.

7.1.9 Pressure test #1.9, 27-28 Jan. 1984

Test #1.9 was an attempt to sustain a radial pressure of 40 MPa and an axial piston pressure of 40 MPa. The procedure was identical to that for test #1.6. The test results in Fig.7c show a small pressure loss (<2%) over 5 hours followed by a massive 10% pressure loss in the radial pressure circuit traced to the failure of an instrument cable "feedthrough". The precise time and nature of the failure was not recorded since it occurred overnight.

Table 7a : Summary of Pressure Test Series #1

Test #	Date	Axial Press. (MPa)	Radial Press. (MPa)	Duration (hrs)
1.1	20-21 Jan 84	7.5	7.5	19.5
1.2	21-22 Jan 84	10	10	21.5
1.3	22-23 Jan 84	20	20	21.5
1.4	23 Jan 84	7.5	0	6
1.5	23-24 Jan 84	10	0	16
1.6	24-25 Jan 84	20	10	15
1.7	25-26 Jan 84	30	20	17.5
1.8	26-27 Jan 84	40	30	17
1.9	27-28 Jan 84	40	40	25.5

7.2 Pressure test series #2

The first series of pressure tests revealed two deficiencies : the temperature sensitivity of the small accumulators, and the tendency for "feedthrough" failure at pressures in excess of 30 MPa. For the second series of pressure tests, the "plumbing" system was restructured to eliminate the small accumulators (see Fig.4c) and the "feedthroughs" were replaced.

7.2.1 Pressure test #2.1, 16-17 Feb. 1984

This test is essentially a repeat of test #1.5 with zero radial pressure and an axial pressure of 10 MPa. A pressure drop of 0.7 MPa in 18.5 hours (compared with 0.5 in 16 hours in test #1.5) was recorded as shown in Fig.7d. Problems with "creep" following load increments have been eliminated by the new "plumbing" system.

7.2.2 Pressure test #2.2, 17-20 Feb. 1984

This test is essentially a repeat of test #1.6 with 10 MPa radial

pressure and an axial pressure of 20 MPa. Radial pressure drops of 0.2 MPa in 24 hours and 0.3 MPa in 42 hours (compared with 0.05 MPa in 16 hours in test #1.6) and axial pressure drops of 0.7 MPa in 24 hours and 0.3 MPa in 42 hours (compared with 0.3 MPa in 16 hours in test #1.6); were recorded as shown in Fig.7d.

7.2.3 Pressure test #2.3, 20 Feb. 1984

This test is essentially a repeat of test #1.7 with 20 MPa radial pressure and an axial pressure of 30 MPa. Fig.7d shows radial and axial pressure drops over a period of 2 hours were zero and 0.3 MPa respectively (compared with 0.1 MPa for both pressures in 16 hours in test #1.7).

Tests #2.1 to #2.3 involved comparable pressure drops to those observed in #1.5 to #1.7 but thermal settling time after pressure increments proved unnecessary. Following test #2.3 a second "feedthrough" failure occurred and the test series was prematurely terminated.

Table 7b : Summary of Pressure Test Series #2

Test #	Date	Axial Press. (MPa)	Radial Press. (MPa)	Duration (hrs)
2.1	23-24 Jan 84	10	0	18.5
2.2	24-25 Jan 84	20	10	66
2.3	25-26 Jan 84	30	20	2

7.3 Pressure test series #3

Following the second "feedthrough" failure the "old" (1978 vintage) "feedthroughs" were discarded and some new ones made with design modifications to minimise the possibility of failure of the epoxy-metal bond. The modified "feedthroughs" were tested at high pressure for 112 hours prior to acceptance.

7.3.1 Pressure test #3.1, 27-28 Feb. 1984

Test #3.1 is essentially a repeat of tests #1.7 and #2.3 with a radial pressure of 20 MPa and an axial piston pressure of 30 MPa. Radial and axial pressure drops over 22.5 hours were 0.07 and 0.8 MPa respectively as shown in Fig.7e. These are comparable with previous results.

7.3.2 Pressure test #3.2, 29 Feb.-1 Mar. 1984

Test #3.2 is a repeat of test #1.8 with a radial pressure of 30 MPa and an axial pressure of 40 MPa. Radial and axial pressure drops of -0.1 and +0.1 MPa respectively were recorded over a period of 20 hours shown in Fig 7e. These results compare well with drops of 0.3 and 0.7 MPa in test #1.8 over 17 hours.

7.3.3 Pressure test #3.3, 1-5 Mar. 1984.

Test #3.3 is the final pressure test at a radial pressure of 40 MPa and the maximum axial pressure of 50 MPa for a period of 90.5 hours. The radial pressure loss was 0.1 MPa and the axial pressure drop 1.0 MPa. The data are plotted in Fig. 7e.

Table 7c : Summary of Pressure Test Series #3

Test #	Date	Axial Press. (MPa)	Radial Press. (MPa)	Duration (hrs)
3.1	28-29 Feb 84	30	20	22.5
3.2	29 Feb-1 Mar 84	40	30	19
3.3	1-5 Mar 84	50	40	90.5

7.4 Conclusions from pressure tests

The pressure test series lead to the elimination of the small, temperature-sensitive, accumulators from the hydraulic circuits in favour of direct control using the main accumulator. Feedthrough design for sensor cables was also modified.

Pressure losses are greatest at low cell pressures since the pressure seals are most effective when under a high load.

With the modified systems it is found that the magnitude of the daily pressure loss is less than half the pressure increment that must be applied to move the axial piston, and that the "slow-leakage" rate is very small. The pressure test series have shown that the cells can be maintained at constant pressure over extended periods and that very few pressure adjustments are necessary.

FIG. 7a PRESSURE TESTS #1.1 - #1.3:
pressure-time curves under
hydrostatic triaxial conditions.

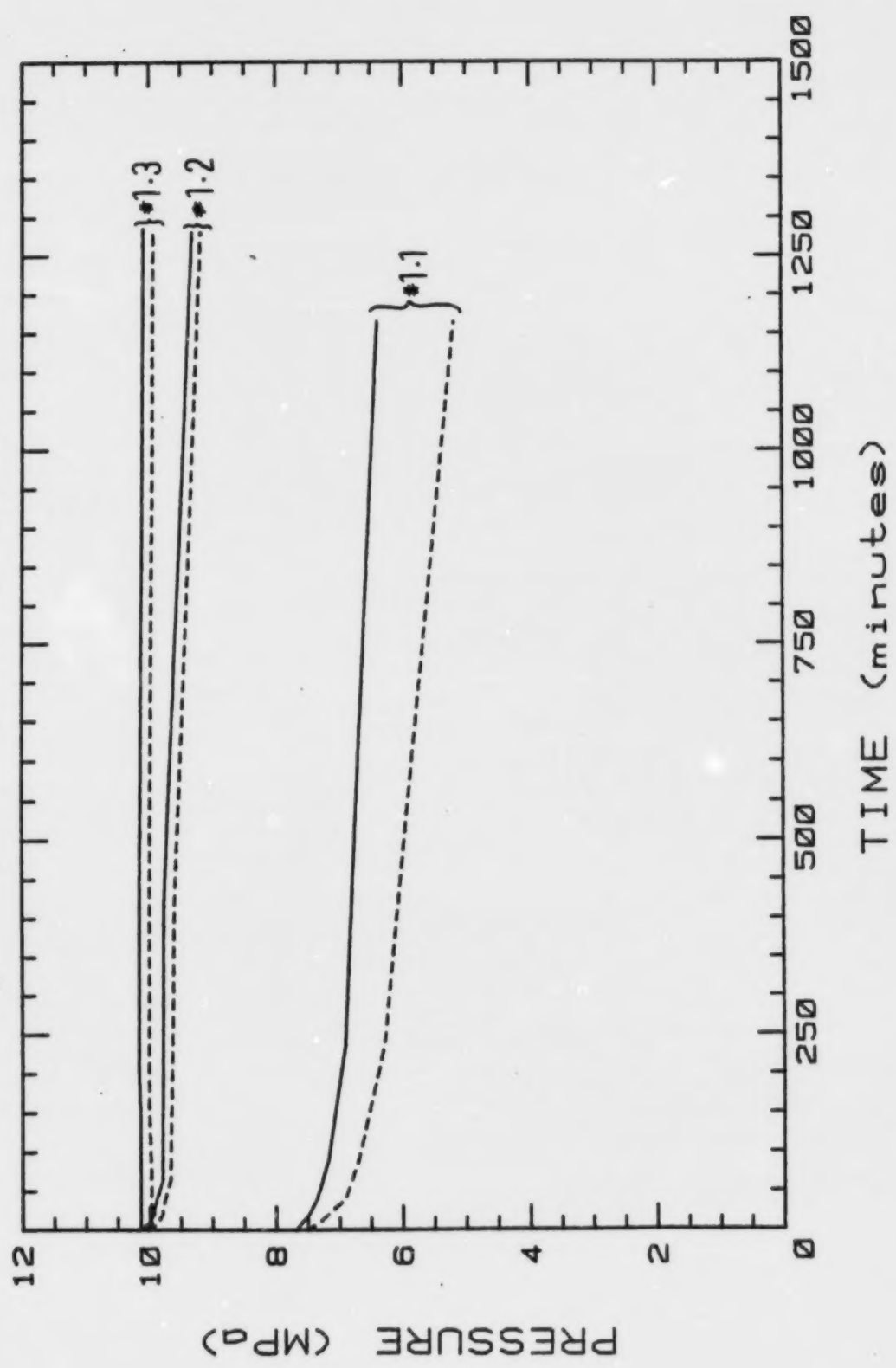


FIG. 7b PRESSURE TEST #1.4:
pressure-time curve for incremental
loading under uniaxial conditions.

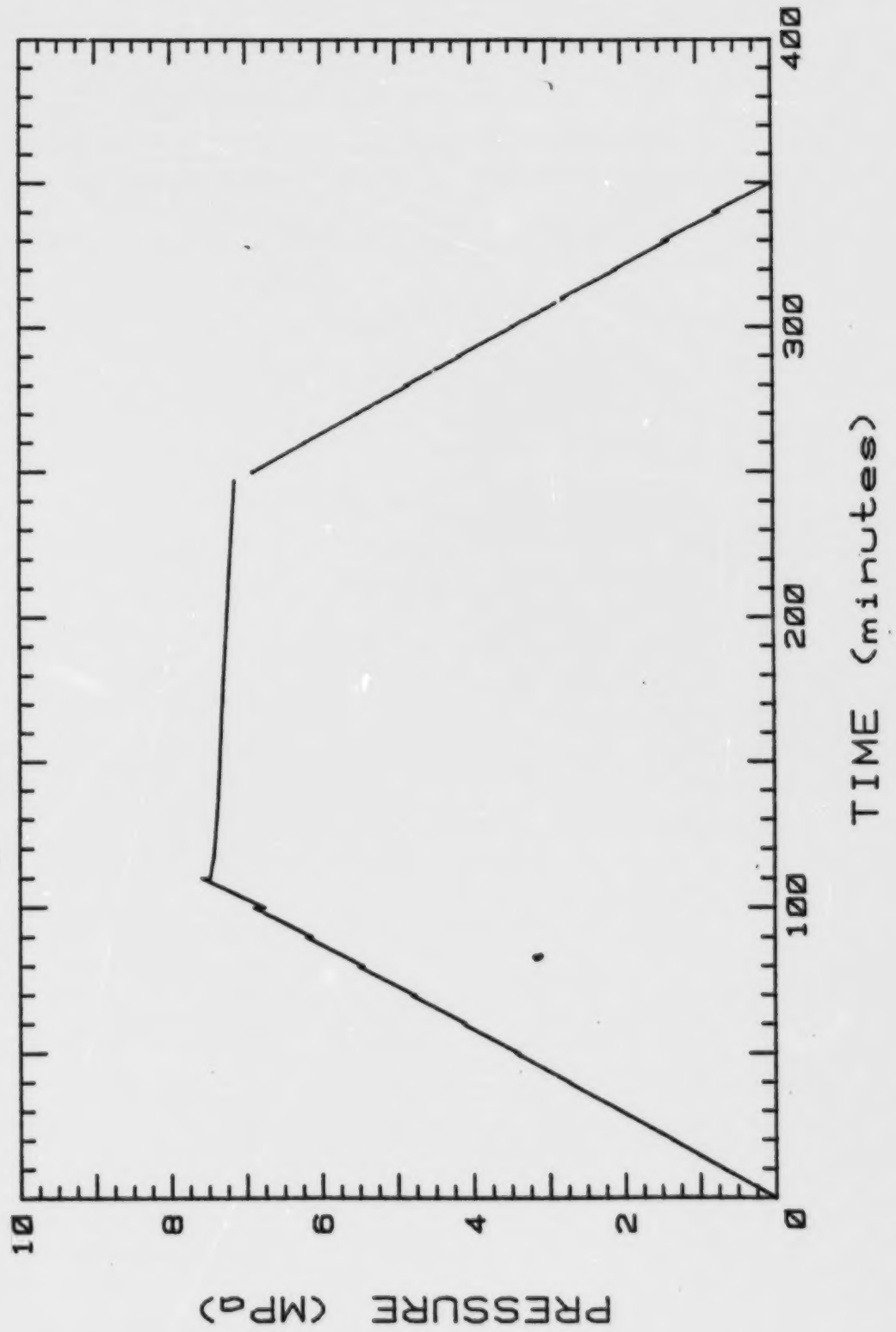


FIG. 70 PRESSURE TESTS #1.5 - #1.9:
pressure-time curves under
triaxial conditions.

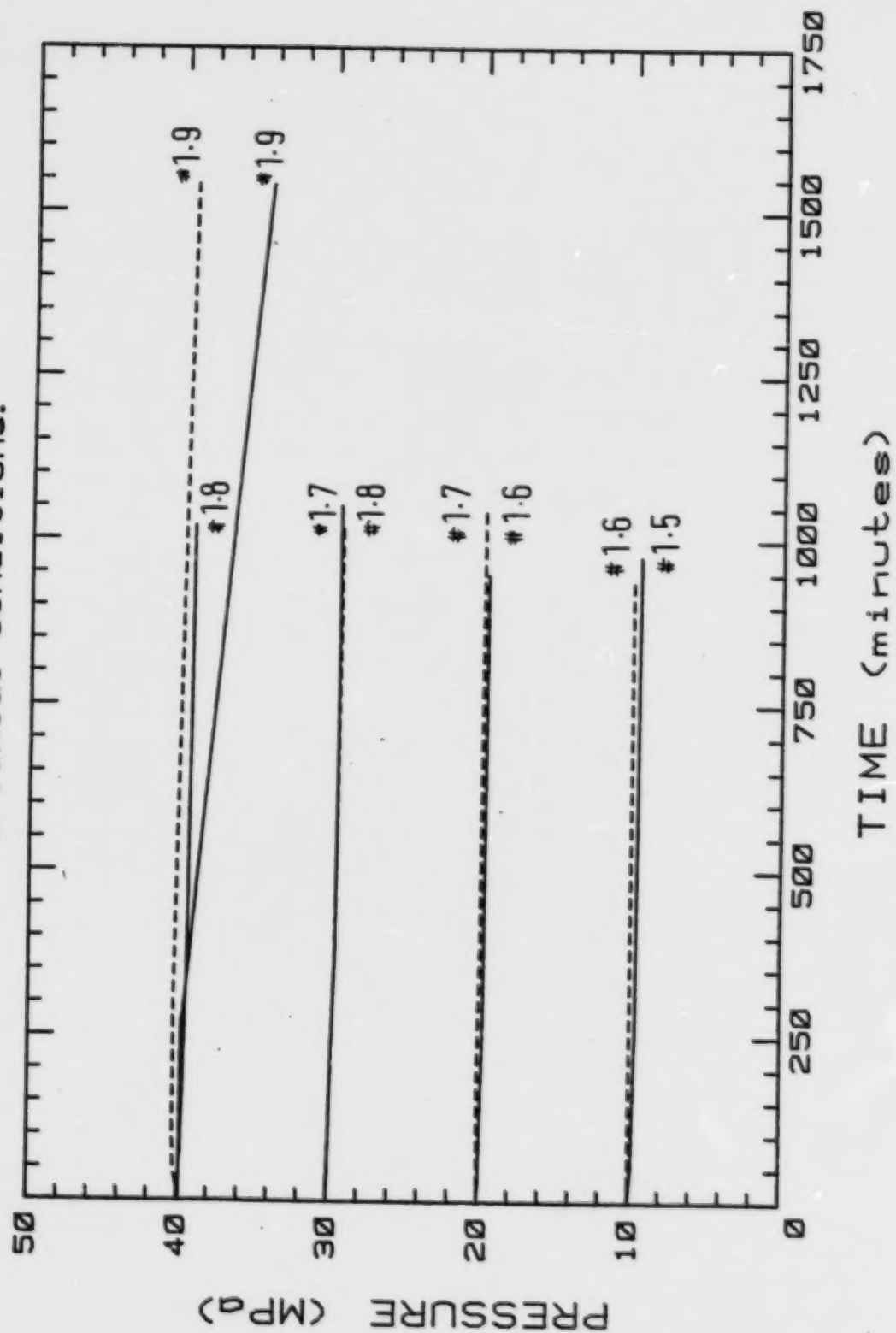


FIG. 7d PRESSURE TESTS #2.1 - #2.3.
pressure-time curves under
triaxial conditions.

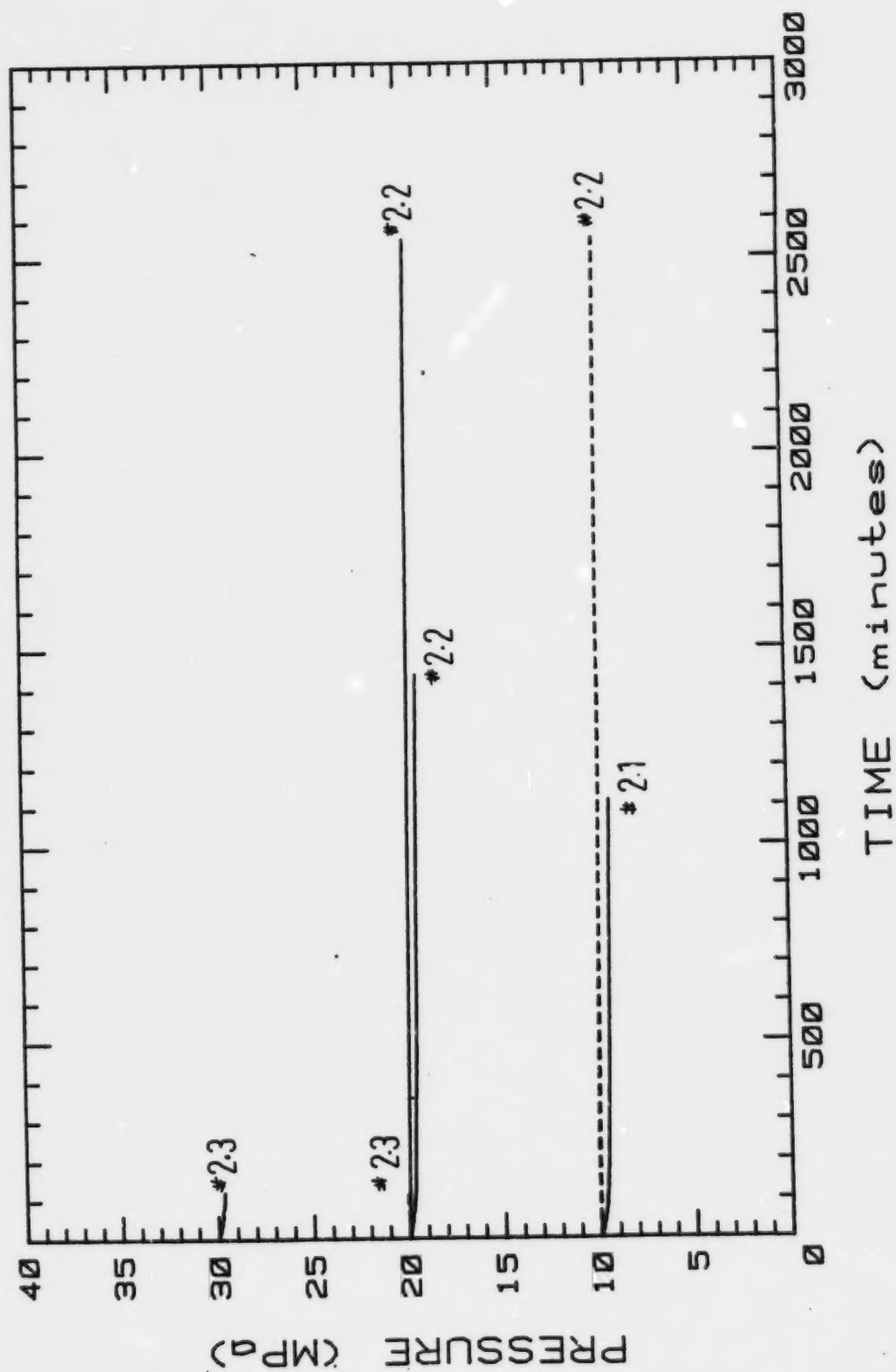
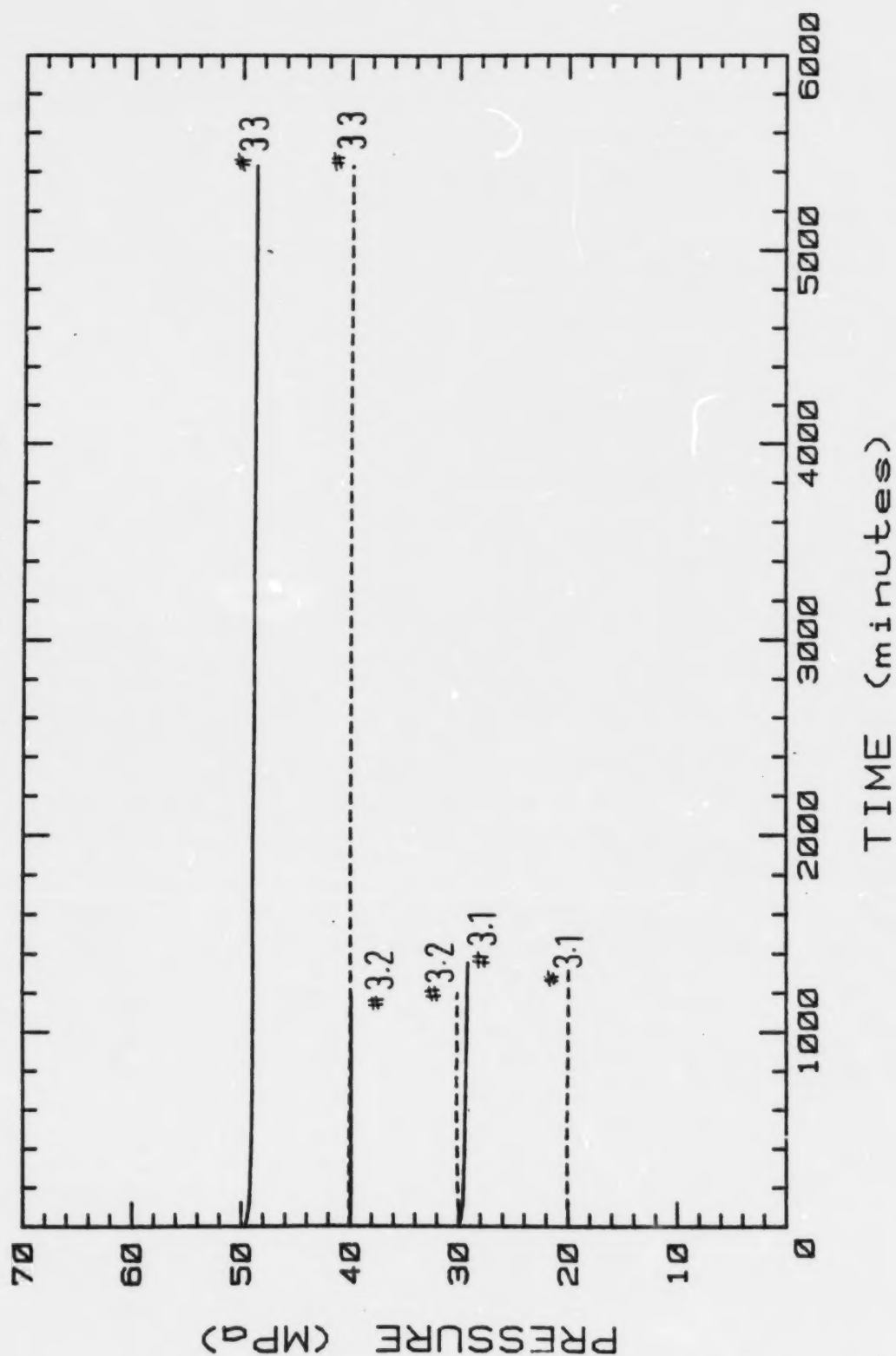


FIG. 7a PRESSURE TESTS #3.1 - #3.3:
pressure-time curves under
triaxial conditions.



8. TRIAXIAL LOAD TESTS

8.1 Triaxial load test series #4

The first series of load tests were carried out on the aluminium test cylinder. They comprise a sequence of loading and unloading experiments at various radial and axial pressures designed to check out the symmetry of loading and the automatic logging procedures for pressures, displacements and strains.

The tests were normally carried out immediately prior to a constant pressure test (although not for every test). All of the tests were repeated after the elimination of the small pressure accumulators so that every test is at least a duplicate; in some cases even triplicate tests were carried out. One of the diametral strain gauges failed in early February so that the later tests used a single diametral strain sensor (and 3 vertical gauges).

The duplicate and triplicate tests demonstrate the ability of the equipment to generate reproduceable data. The "stress paths" for the test series (in p - q stress space) are plotted in Fig.8a. The parameter p is the mean of the axial and radial stresses and q is half the difference between the axial and radial stresses (or half the deviator stress).

8.1.1 Uniaxial load tests #4.1, 20 Jan. and 16 Feb. 1984

Three uniaxial load tests were carried out. For test #4.1a on 20 Jan. and test 4.1b on 16 Feb., the axial stress was incrementally increased by 2 MPa every 5 mins (.40 MPa/min) to a maximum value of about 22 MPa. In test #4.1c on 16 Feb, the axial stress was increased in equal increments of 4 MPa every 10 mins (.40 MPa/min) to a maximum value of about 29 MPa. The stress-strain curves (average strain) are shown on the composite plot Fig.8b. Diametral strains are shown as solid lines and axial strains as dashed lines.

8.1.2 Triaxial load tests #4.2, 24 Jan. and 17 Feb. 1984

Two tests were carried out at a nominal confining pressure of 10 MPa and a maximum axial stress of about 32 MPa. The axial stress was raised from 10 MPa to 32 MPa in 2 MPa increments at 10 minute intervals (.20 MPa/min). The resultant stress-strain curves are shown in Fig.8b.

8.1.3 Triaxial load tests #4.3, 25 Jan., 20 Feb. and 27 Feb. 1984

Three tests were carried out at a nominal confining pressure of 20 MPa and a maximum axial stress of about 42 MPa. The axial stress was raised from 20 MPa to 42 MPa in 2 MPa increments at 10 minute

intervals (.20 MPa/min). The resultant stress-strain curves are shown in Fig.8b.

8.1.4 Triaxial load tests #4.4, 26 Jan. and 28 Feb. 1984

Two tests were carried out at a nominal confining pressure of 30 MPa and a maximum axial stress of about 52 MPa. The axial stress was raised from 30 MPa to 52 MPa in 2 MPa increments at 10 minute intervals (.20 MPa/min). The resultant stress-strain curves are shown in Fig.8b.

8.1.5 Triaxial load tests #4.5, 27 Jan. and 1 Mar 1984

Two tests were carried out at a nominal confining pressure of 40 MPa and a maximum axial stress of about 62 MPa. The axial stress was raised from 40 MPa to 62 MPa in 2 MPa increments at 10 minute intervals (.20 MPa/min). A third test was conducted with the same confining pressure but the axial stress was raised to 68 MPa at the same rate. Fig.8b includes the resultant stress-strain curves.

8.1.6 Triaxial load test series #4 results and conclusions

One of the many checks that were made during the test procedures was aimed at determining the "evenness" with which the loads are distributed through the sample. This is best seen by comparing the individual strain-gauge readings for the load tests.

Table 8a shows the individual strain gauge readings at the peak value for each of the triaxial load test series #4 experiments. All readings are in microstrains (microns/metre) and are accurate to ± 5 . Stress values are given in MPa. The tests give an average value for Young's Modulus of 73 GPa (published value for Al is 72 GPa) and 0.30 for Poisson's Ratio (published value 0.33).

Table 8a also demonstrates that even loading is achieved for all the tests at high stress levels (#4.3 to #4.5). At lower stress levels (#4.1 and #4.2) there is a distinct improvement for the later tests. This improvement is partly attributed to the better performance of the self-adjusting, hollow-ground, lower platen with increasing usage, but the major load asymmetry shown in tests #4.1a and #4.2a was caused by the use of a pin which prevents slippage on the platens. It was used for these tests only.

It is thought that the self-adjusting mechanism presented a significant frictional resistance at first which decreased rapidly as it was "worn-in" by use.

Table 8a : Summary of Triaxial Load Test Series #4

Test #	Axial Conf.		Vertical gauges				Diametral gauges		
	Stress (MPa)	Stress (MPa)	SG#1 (uS)	SG#2 (uS)	SG#3 (uS)	Av. (uS)	SG#4 (uS)	SG#5 (uS)	Av. (uS)
4.1a	22	0	- 80	-582	-299	-320	+ 62	+133	+ 97
4.1b	22	0	-231	-373	-340	-315	N/A	+ 98	+ 98
4.1c	29	0	-323	-470	-445	-413	N/A	+130	+130
4.2a	32	10	-196	-400	-325	-307	+117	+117	+117
4.2b	32	10	-246	-357	-333	-312	N/A	+104	+104
4.3a	42	20	-258	-331	-304	-298	+110	+110	+110
4.3b	42	20	-269	-323	-306	-299	N/A	+ 98	+ 98
4.3c	42	20	-271	-339	-313	-308	N/A	+ 99	+ 99
4.4a	52	30	-260	-309	-307	-292	N/A	+101	+101
4.4b	52	30	-287	-292	-294	-291	N/A	+102	+102
4.5a	62	40	-290	-287	-288	-288	N/A	+102	+102
4.5b	62	40	-282	-284	-286	-284	N/A	+102	+102
4.5c	68	40	-362	-402	-394	-386	N/A	+126	+126

All strain gauge readings are relative to the initial hydrostatic condition before the axial stress was raised. See Fig.8b.

In all series #4 load tests strains were measured by both bonded strain gauges and potentiometers. The potentiometer strains were consistently higher than those recorded from strain gauges. Much of the difference was attributed to the initial "seating strains" in the upper platen and end seal assembly. Since the strain gauge readings were consistent with the GELUS tests and the published elastic properties for aluminium, it was concluded that the problem was associated with the potentiometer positioning.

8.2 Triaxial load tests series #5

A series of stress-strain response curves were determined for the aluminium cylinder at constant axial pressure by incrementing the confining pressure to restore hydrostatic conditions. Stress paths for the test series are given in Fig.8c. The tests were typically carried out immediately after a pressure test with few exceptions. Three axial and two radial strain measurements were usually made.

8.2.1 Triaxial load tests #5.1, 24 Jan. and 17 Feb. 1984

Two tests were carried out at an initial axial stress of 29 MPa. The confining pressure was raised from zero to 10 MPa in about 1.4

MPa increments at 10 minute intervals (.14 MPa/min) to restore hydrostatic conditions. (Any confining pressure increase is accompanied by a reduction in axial stress due to its action on the load piston). The composite plot Fig.8d shows the resultant stress-strain curves; diametral strains (solid lines) and axial strains (dashed lines).

8.2.2 Triaxial load tests #5.2, 25 Jan. and 20 Feb. 1984

Two tests were carried out at an initial axial stress of 49 MPa. The confining pressure was raised from 10 to 20 MPa in about 1.4 MPa increments at 10 minute intervals (.14 MPa/min) to restore hydrostatic conditions. Fig.8d shows the resultant stress-strain curves.

8.2.3 Triaxial load tests #5.3, 26 Jan. and 28 Feb. 1984

Two tests were carried out at an initial axial stress of 59 MPa. The confining pressure was raised from 20 to 30 MPa in about 1.4 MPa increments at 10 minute intervals (.14 MPa/min) to restore hydrostatic conditions. Fig.8d shows the resultant stress-strain curves.

8.2.4 Triaxial load tests #5.4, 27 Jan. and 1 Mar 1984

Two tests were carried out at an initial axial stress of 69 MPa. The confining pressure was raised from 30 to 40 MPa in about 1.4 MPa increments at 10 minute intervals (.14 MPa/min) to restore hydrostatic conditions. Fig.8d shows the resultant stress-strain curves.

8.2.5 Triaxial load test series #5 results and conclusions

The results of the hydrostatic compression phases of test series #5 are summarized in Table 8b. The aluminium test cylinder gave a compressibility value of $.0134 \text{ GPa}^{-1}$ * compared with an expected value of $.0164 \text{ GPa}^{-1}$ (based on the Young's modulus of 73 GPa and Poissons Ratio of 0.30 obtained from test series #4). The published values for aluminium is $.0150 \text{ GPa}^{-1}$.

The results plotted in Fig.8d demonstrate behaviour consistent with the elastic properties of aluminium. These tests together with series #4 gave confidence in the even application of both axial and cell pressures.

Stress rates in test series #4 and #5 varied from 0.40 to 0.10 MPa/min. These rates of loading are quite low. For determination of "elastic" moduli, ISRM recommend much higher stress rates from 30 to 60 MPa/min. These rates can easily be achieved in the LSTF but lower rates were deliberately chosen to check for instrumental

* This notation should be read as GPa to the power of -1

drift and potential leaks in the hydraulic circuits.

Table 8b : Summary of Triaxial Load Test Series #5

Test #	Axial Conf.		Vertical gauges				Diametral gauges		
	Stress (MPa)	Stress (MPa)	SG#1 (uS)	SG#2 (uS)	SG#3 (uS)	Av. (uS)	SG#4 (uS)	SG#5 (uS)	Av. (uS)
5.1a	10	10	- 55	- 59	- 54	- 56	- 2	- 48	- 25
5.1b	10	10	- 15	- 96	- 71	- 61	N/A	- 45	- 45
5.2a	20	20	-126	-130	-125	-127	N/A	- 75	- 75
5.2b	20	20	- 77	-158	-133	-123	N/A	- 72	- 72
5.3a	30	30	-202	-206	-201	-203	N/A	-102	-102
5.3b	30	30	-156	-237	-212	-202	N/A	- 99	- 99
5.4a	40	40	-288	-292	-287	-288	N/A	-129	-129
5.4b	40	40	-242	-323	-298	-289	N/A	-126	-126

Strains are cumulative from initial zero hydrostatic.

8.3 Triaxial load test series #6

This series of tests was carried out on 200 mm diameter x 400 mm length potash core R1 using 2 or 3 axial strain measuring devices (resistance wire gauges or transducers) and 2 diametral resistance wire gauges.

The tests were designed primarily to evaluate the performance of the LSTIF over a wide range of stress and strain conditions and secondarily to determine the rheological characteristics of the test specimen. Because of the high cost of sample preparation and installation, multiple tests were carried out on the same specimen. Stress paths for the test series are given in Fig.8e.

8.3.1 Triaxial load test #6.1, 3 Apr. 1984

The core was uniaxially loaded and unloaded to a maximum axial stress of 5.2 MPa. Axial (2 gauges) and diametral (2 gauges) strains were monitored by resistance wire gauges. Three linear pots were attached to the sample on metal bands outside the "ecosil" jacket in order to directly monitor vertical strain. The load was incremented by around 0.3 MPa every 3 minutes (.10 MPa/min). Deviator stress is shown plotted against axial (dashed line for gauges, dotted line for pots) and diametral (solid line) strain in Fig.8f-a.

8.3.2 Triaxial load test #6.2, 5 Apr. 1984

For test #6.2, diametral gauges and axial potentiometers were used to monitor strain. All axial gauges failed between test #6.1 and test #6.2. The confining pressure was held constant at 10 MPa and the axial stress raised from the initial hydrostatic condition to 16.4 MPa (deviator stress 6.4 MPa) and then returned to hydrostatic by deviator stress increments of about 0.3 MPa every 5 minutes (.06 MPa/min). A period of approximately 12 hours was allowed for "consolidation" at the new hydrostatic stress level prior to testing. Deviator stress is shown plotted against axial and diametral strain in Fig.8f-a.

8.3.3 Triaxial load test #6.3, 6 Apr. 1984.

For test #6.3, diametral gauges and axial pots were used to monitor strain. The hydrostatic stress was raised from 10 to 20 MPa then, following a "consolidation" period of about 12 hours, a load-unload cycle was performed with a maximum deviator stress of 6.4 MPa by applying incremental changes of approximately 0.3 MPa every 5 minutes (.06 MPa/min). Fig.8f-a shows deviator stress plotted against axial and diametral strain.

8.3.4 Triaxial load test #6.4, 7 Apr. 1984.

The hydrostatic stress was raised to 30 MPa for test #6.4. No changes in instrumentation were made. After a "consolidation" period of about 12 hours, a load-unload cycle was performed with a maximum deviator stress of 6.4 MPa by applying incremental changes of approximately 0.3 MPa every 5 minutes (.06 MPa/min). Fig.8f-a shows deviator stress plotted against axial and diametral strain.

8.3.5 Triaxial load test #6.5, 9 Apr. 1984.

The hydrostatic stress was raised to 40 MPa for test #6.5. No changes in instrumentation were made. After a "consolidation" period of about 12 hours, a load-unload cycle was performed with a maximum deviator stress of 6.4 MPa by applying incremental changes of approximately 0.3 MPa every 5 minutes (.06 MPa/min). Fig.8f-a shows deviator stress plotted against axial and diametral strain.

8.3.6 Triaxial load test #6.6, 10 Apr. 1984.

Core R1 was retained at 40 MPa hydrostatic for a further 12 hour period and then loaded to the maximum possible axial stress by applying deviator stress using increments of about 0.6 MPa every 5 minutes (.12 MPa/min). An axial stress of 72.7 MPa was reached without apparent failure. Fig.8f-b shows deviator stress plotted against axial strain from pots (dotted line) and diametral strain from gauges (solid line).

8.3.7 Triaxial test series #6 results and conclusions

Potentiometers used in test series #6 were attached to metal bands around the outside of the jacket, close to the upper and lower sample ends. These attachments were subsequently discovered to be prone to slippage (towards one another), thus recording an overestimate of strain.

All axial strain gauges became inoperative after test #6.1 but since the gauges and specimen had survived together for more than 140 days, this was not regarded as a serious failure. The two diametral gauges survived for virtually the full test series (failing late in test #6.6).

No problems were encountered in maintaining or adjusting either the axial or confining pressures for the "softer" evaporite cores. Leakage and piston stick problems were not encountered. Data logging systems performed as expected and presented no problems.

Table 8c : Summary of Triaxial Load Test Series #6

Test #	Axial Stress (MPa)	Conf. Stress (MPa)	Av.Vert.gauge Load (uS)	Av.Vert.gauge Unload (uS)	Av.Vert.Pot Load (uS)	Av.Vert.Pot Unload (uS)	Av.Diam.gauge Load (uS)	Av.Diam.gauge Unload (uS)
6.1	5.2	0	-239	- 46	-793	-448	+119	+ 44
6.2	16.4	10	N/A	N/A	-1144	-1094	+230	+171
6.3	26.4	20	N/A	N/A	-989	-936	+198	+132
6.4	36.4	30	N/A	N/A	-722	-678	+162	+105
6.5	46.4	40	N/A	N/A	-446	-416	+121	+ 66
6.6	73.4	40	N/A	N/A	-23237	N/A	+9674	N/A

Strains are relative to zero after hydrostatic consolidation.

The results shown in the Figs.8f-a and 8f-b and summarized in Table 8c, show a consistently reduced sensitivity to the same deviator stress with increasing confining pressure. At a loading rate of .1 MPa/min, in test #6.1, more strain was recovered on unloading than in the subsequent tests at .06 MPa/min, demonstrating that significant creep strains were accumulating during the load tests.

The major disparity between bonded strain gauge data and that from potentiometers in test #6.1 is, at least in part, attributed to slippage of the potentiometer attachment bands.

The cumulative total strain in core R1 was provided by comparing its initial and final dimensions. Little or no "barrelling" was

observed, and a total axial shortening of 4.2% with an average diametral extension of 1.5% were found. Since the record of the strain history of specimen R1 is incomplete, no useful estimate of the amount of slippage can be made.

8.4 Triaxial load test series #7

This series of tests was carried out on 200 mm diameter x 400 mm length potash core C1 using 3 axial resistance wire gauges and 3 linear potentiometers attached on bands. Two diametral resistance wire gauges were applied but one failed (or became disconnected) during the sample preparation/cell-load procedures and was never functional. Gauge replacement after jacketing and cell-loading is a lengthy and expensive procedure so the test was carried out with a single diametral gauge.

The tests were designed primarily to evaluate the comparative performance of the axial gauges and potentiometers over a wide range of stress and strain conditions. Determination of the rheological characteristics of core C1 was not a prime objective. Pots and strain gauges recording vertical strains were arranged symmetrically in pairs to enable sensor-by-sensor comparisons to be made. Stress paths for the test series are given in Fig.8g.

8.4.1 Triaxial load test #7.1, 24 Apr. 1984

The core was uniaxially loaded and unloaded to a maximum axial stress of 5.2 MPa. The load was incremented by approximately 0.3 MPa every 3 minutes (.10 MPa/min). Deviator stress is shown plotted against axial (dashed line for gauges, dotted line for pots) and diametral (solid line) strain in Fig.8h-a.

8.4.2 Triaxial load test #7.2, 25 Apr. 1984

The confining pressure was gradually raised to 10 MPa and then held constant for about 12 hours. The axial stress was then raised from the initial hydrostatic condition to 16.4 MPa (deviator stress 6.4 MPa) and then returned to hydrostatic by deviator stress increments of about 0.3 MPa every 5 minutes (.06 MPa/min). Deviator stress is plotted against axial and diametral strain in Fig.8h-a.

8.4.3 Triaxial load test #7.3, 27 Apr. 1984

The hydrostatic stress was raised from 10 to 19 MPa and, following a "consolidation" period of approximately 36 hours, a load-unload cycle was performed with a maximum deviator stress of 5.1 MPa by applying incremental changes of approximately 0.3 MPa at 5 minute intervals (.06 MPa/min). Fig.8h-a shows the deviator stress plotted against axial and diametral strain. One of the

three axial strain gauges failed immediately prior to test #7.3.

8.4.4 Triaxial load test #7.4, 30 Apr. 1984

The hydrostatic stress was again raised to 25 MPa for test #7.4 and following a "consolidation" period of about 36 hours, a load-unload cycle was performed with a maximum deviator stress of 5.1 MPa by increments of approximately 0.3 MPa every 5 minutes (.06 MPa/min). Fig.8h-a shows deviator stress plotted against axial and diametral strain.

8.4.5 Triaxial load test #7.5, 1-9 May 1984

The hydrostatic stress was retained at 25 MPa for test #7.5. This test represents the first attempt to monitor creep in the LSTF. A deviator stress of 6.1 MPa was applied by incrementing the axial pressure by approximately 1.5 MPa every 5 minutes. This triaxial stress condition was maintained for a period 192 hours whilst the strain was continuously monitored. Fig.8h-a shows deviator stress plotted against axial and diametral strain for the initial loading phase of the test. Fig.8i shows axial strain and diametral strain plotted against time for the creep phase of the test.

8.4.6 Triaxial load test #7.6, 9 May 1984

After the creep phase of test #7.5, the axial stress was raised at the rate of about 0.6 MPa every 5 minutes (.12 MPa/min) until the core "failed" at a peak axial stress of about 75 MPa (about 50 MPa deviator stress). Fig.8h-b shows deviator stress plotted against axial and diametral strain.

8.4.7 Triaxial load test series #7 results and conclusions

Comparison of vertical strain gauge and pot results showed that the later data for tests #7.5 and #7.6 are consistent. Although in some cases strain gauge bonding may be suspect and potentiometer attachments may slip, careful sample preparation and installation can avoid these problems.

In test #7.1 to #7.4 there is little correspondence between the strains measured by gauges and pots. In test #7.1, close examination of the data reveals that the loading was very uneven. Core C1 had relatively rough, sub-parallel ends and tests #7.1 to #7.4 are thought to give erratic strain values due to the "flattening" of the core. It is concluded that some degree of end preparation over and above rough sawing is required.

The total axial strain over test series #7 was about 47 mm (11.6%), the total diametral strain was 9.5 mm (4.4%). The core underwent a volumetric dilation of approximately 2.8% and was

*Failure is defined as the condition when the sample strains at such a rate that the axial load cannot be maintained.

"barrel-shaped" after removal from the cell. The "barrelling" is attributed to the rapid loading to failure at the end of the creep phase of the test. The attachment bands for the pots severely restricted the diametral expansion of the core ends and to avoid this problem in future tests, a new attachment procedure was adopted.

Pots are preferred for axial strain measurements since results are available at failure even when strains are very large (15%). Although one diametral gauge "failed" prior to test series #7, the survival of at least one diametral gauge to very near the point of failure has been established in test series #6 and #7.

No problems were encountered with axial or confining stress maintenance using either manual control valves or automatic control valves. Data logging systems performed as expected and presented no problems.

Table 8d : Summary of Triaxial Load Test Series #7

Test #	Axial Stress (MPa)	Conf. Stress (MPa)	Av.Vert.gauge Load (uS)	Av.Vert.gauge Unload (uS)	Av.Vert.Pot. Load (uS)	Av.Vert.Pot. Unload (uS)	Av.Diam.gauge Load (uS)	Av.Diam.gauge Unload (uS)
7.1	5.2	0	-597	-263	-921	-784	+ 44	+ 0
7.2	16.6	10	-1965	-1798	-2315	-2360	+334	+286
7.3	23.7	19	-380	-418	-1430	-1426	+439	+406
7.4	30.4	25	-301	-320	-1205	-1191	+401	+372
7.5	31.2	25	-340	N/A	-474	N/A	+166	N/A
7.5*	31.2	25	-1802	N/A	-1817	N/A	+507	N/A
"	"	"	-2694	N/A	-2778	N/A	+800	N/A
"	"	"	-3226	N/A	-3359	N/A	+970	N/A
"	"	"	-3599	N/A	-3771	N/A	+1093	N/A
"	"	"	-3792	N/A	-4000	N/A	+1158	N/A
"	"	"	-4086	N/A	-4316	N/A	+1258	N/A
"	"	"	-4310	N/A	-4575	N/A	+1361	N/A
"	"	"	-4513	N/A	-4760	N/A	+1430	N/A
7.6**	40.0	25	-2539	N/A	-2482	N/A	+930	N/A
"	50.0	"	-11188	N/A	-11063	N/A	+4438	N/A
"	60.0	"	-30000	N/A	-30126	N/A	+13216	N/A
"	74.9	"	-30000+	N/A	-85883	N/A	N/A	N/A

Strains are relative to zero after initial hydrostatic consolidation.

* Strains are relative to zero at the end of the final loading cycle and represent creep strains at 24 hour intervals.

** Strains at failure are relative to zero at the end of the creep period.

8.5 Triaxial load test series #8

This series of tests was carried out on 200 mm diameter x 400 mm length potash core C2 using 3 axial resistance wire gauges and 2 diametral resistance wire gauges.

The tests were designed primarily to obtain a more complete set of diametral strain measurements and to determine the triaxial strength of core C2 under conditions of rapid loading. Stress paths for this short test series are given in Fig.8j.

8.5.1 Triaxial load test #8.1, 25 May 1984

The core was triaxially loaded at a confining pressure of 10 MPa to a maximum axial stress of 23.6 MPa following 24 hours "consolidation" under hydrostatic stress. The load was incremented at the rate of 0.6 MPa every 2 minutes (.29 MPa/min). At 23.6 MPa axial load, the "o" ring seals in the axial pressure supply solenoid valve failed and the sample had to be unloaded. Deviator stress is shown plotted against axial (dashed line) and diametral strain (solid line) in Fig.8k.

8.5.2 Triaxial load test #8.2, 28 May 1984

This test represents a repeat of test #8.1 after replacing the faulty solenoid valve in the axial pressure hydraulic circuit. The confining pressure was gradually raised to 10 MPa and then held constant for about 12 hours. The axial stress was then raised from the initial hydrostatic condition to fail the core C2. The peak axial stress prior to failure was 48.6 MPa (deviator stress 38.6 MPa). The axial stress was increased by increments of about 1.5 MPa every 5 minutes (.29 MPa/min). Deviator stress is plotted against axial and diametral strain in Fig.8k.

8.5.3 Triaxial load test series #8 results and conclusions

An important finding of test series #8 was O-ring failure. Following this test, a series of failures of the old (6-8 years) "o" rings in the solenoid control valves delayed the testing of the computer control systems. All the old rings seem to have a very limited operational life and need urgent replacement. Unfortunately, the replacement seals were not readily available.

Much more rapid loading can be achieved but in test series #8, the solenoid valve seals were inspected for signs of leakage with every load increment. With full computer control, the load could be applied in less than 60 seconds.

Two diametral strain gauges provided data up to the moment of failure. One of the three vertical strain gauges failed prematurely. Pots were not used since large creep strains were

not anticipated and gauges are more sensitive for small strains.

The short test series #8 gives an estimate of the shear strength of core C2 under rapid loading conditions with a confining stress of 10 MPa. The value obtained of 48.6 MPa is within the range of published data for potash.

The stress-strain data shown in Fig.8k and summarized in Table 8e indicate lower strains for equal loads in the second test #8.2. This is as expected for "creep-prone" materials. Test #8.2 clearly shows a marked decrease in the deformation modulus (stress-strain gradient) immediately prior to failure.

"Barrelling" of the failed core, a feature invariably associated with high loading rates but virtually absent from slowly loaded cores, was extreme for this specimen C2.

Table 8e : Summary of Triaxial Load Test Series #8

Test #	Stress		Vertical gauges				Diametral gauges		
	Axial (MPa)	Conf. (MPa)	SG#1 (uS)	SG#2 (uS)	SG#3 (uS)	Av. (uS)	SG#4 (uS)	SG#5 (uS)	Av. (uS)
8.1	23.3	10	-4733	-5393	-5462	-5196	+1459	+1258	+1359
8.2	48.6	10	N/A	-38036	-37710	-37873	+19770	+16812	+18291

Strains are cumulative from initial zero hydrostatic.

8.6 Triaxial load test series #9

This series of tests was carried out on 200 mm diameter x 400 mm length potash core C3 using 3 axial resistance wire gauges and 3 linear potentiometers. Two diametral resistance wire strain gauges were applied but one failed (or became disconnected) at some stage during the sample preparation/cell-load procedures and was never functional. The second diametral gauge also failed prematurely so that only axial strains were effectively monitored for this test series.

The tests were designed primarily to evaluate the comparative performance of the axial gauges and potentiometers over a wide range of stress and strain conditions, following the development of a method of attaching the pots directly to the core ends by mounting small circumferential plates at equal intervals. A secondary objective of the test was to determine the creep characteristics of core C3. Stress paths for the test series are given in Fig.8l.

8.6.1 Triaxial load test #9.1, 16 June 1984

The confining pressure was gradually raised to 10 MPa and then held constant for about 12 hours. The axial stress was then raised from the initial hydrostatic condition to 36.4 MPa (deviator stress 26.4 MPa) by stress increments of about 1.5 MPa every 5 minutes (.29 MPa/min). Deviator stress is plotted against axial (dashed line for gauges, dotted line for pots) and diametral (solid line) strain in Fig.8m.

This triaxial stress regime was maintained for a period of more than 6 hours whilst the strain was continuously monitored. At this time, the sample "failed" and the test was concluded. Fig.8n shows the axial strain plotted against time for the creep test.

8.6.2 Triaxial load test series #9 results and conclusions

Test #9.1 established reasonable comparability of strain gauge and potentiometer displacement data for the loading phase but was disappointing as a long-term creep test. The deviator stress of 26.4 MPa, chosen to obtain high creep rates at 10 MPa confining stress, proved too high for steady-state creep response. The induced strains caused surface "spalling" of the core resulting in the rupture of the diametral gauges and the anomalous behaviour of all the vertical gauges, due to their total or partial detachment from the main body of the core on spalled blocks. The core failed prematurely after less than 7 hours of very rapid creep.

Table 8f : Summary of Triaxial Load Test Series #9

Test #	Axial Stress (MPa)	Conf. Stress (MPa)	Average vertical strain Gauge (uS)	Pot. (uS)	Diametral gauge SG#5. (uS)
9.1	36.4	10	-17083	-21316	+ 6559
9.1*	36.4	10	-20666	-27248	N/A
	"	"	-21920	-31440	N/A
	"	"	-20054	-35211	N/A
	"	"	-19106	-39665	N/A
	"	"	-18121	-43463	N/A
	"	"	-16999	-48282	N/A
	"	"	-16850**	-59228**	N/A

Strains are relative to zero after hydrostatic consolidation.

* Strains are relative to zero at the start of the final loading cycle and represent creep strains at 1 hour intervals.

** Final strain is after 6.91 hours.

Figs 8m and 8n record the stress-strain behaviour. The erratic behaviour of the strain gauges highlights the advantages of the pot system which, in contrast, yielded very consistent data. The premature failure is attributed in part to pre-existing planes of weakness in the core which was probably obtained an insufficient distance from the mine opening and had been subject to excessive stresses prior to sampling.

8.7 Triaxial load test series #10

This final series of tests was carried out on 200 mm diameter x 400 mm length potash core V1 using 3 axial linear potentiometers and 5 diametral resistance wire gauges in an attempt to obtain reliable volumetric-strains for long-term, creep/relaxation behaviour.

The tests were designed primarily to evaluate the creep/relaxation characteristics of core V1. Stress paths for the test series are given in Fig.8o.

The "o"-ring problem outlined in section 8.5.3 was responsible for a considerable delay in starting test series #10. Since no serviceable valves were available by 1 October 1984, the final test was carried out without computer control of pressures. Constant pressures were maintained through intensifiers operated by gas bottles. Occasional manual intervention was necessary to recharge the intensifiers and correct any "drift".

8.7.1 Triaxial load test #10.1, 1 Oct.- 12 Dec. 1984

Core V1 was consolidated for the period of early July to 1 October 1984 under hydrostatic stresses. A leak in a solenoid valve during the consolidation caused the axial pressure to "drift" from the 10 MPa intended consolidation pressure to more than 20 MPa so that the core was subjected to consolidation for some time at the higher pressure. Since the higher pressure is close to the subsurface ambient pressure, no damage to the core was apparent and the test was continued.

During the long consolidation phase, 2 of the five radial strain gauges failed. The remaining three gauges all failed within 6 days of the start of the creep test. It is thought that these failures were in large part due to the long period of operation and/or the possibly, highly corrosive action of pore fluids. Core C4 was prepared in readiness for a further test which will not form part of this report.

From the initial state of hydrostatic consolidation, the axial pressure was raised from 10 MPa to the test level of around 30 MPa (deviator stress 20 MPa) by stress increments of about 1.5 MPa every 5 minutes (0.29 MPa/min). Deviator stress is plotted against axial (dotted line for pots) strain in Fig. 8p.

axial stress routine was maintained for a period of more than 200 hours whilst the strain was continuously monitored. Fig. 30 shows the axial strain plotted against time for the creep test. The results for test series 410 are summarized in Table 30.

Table 30 : Summary of Triaxial Load Test Series 410

Test #	Axial Stress (MPa)	Conf. Stress (MPa)	Mean Stress (MPa)	Dev. stress (MPa)	Average vert. strain Pot. (%)	Creep rate (0.5/d)
10.1	29.4	10.0	19.7	19.4	0.34	874
10.1*	30.2	10.1	20.1	19.9	1.80	2297
	29.3	10.2	19.8	19.1	2.15	354
	29.5	10.0	19.8	19.5	2.37	582
	29.3	10.0	19.4	19.9	2.67	675
	29.1	10.0	19.5	19.2	2.81	186
	29.8	9.9	19.2	19.9	3.05	442
	29.7	9.9	19.8	19.8	3.12	392
	29.3	10.0	19.8	19.5	3.28	313
	29.6	9.9	19.8	19.7	3.50	348
	29.8	9.9	19.9	19.9	3.64	326
	29.8	9.9	19.9	19.9	3.78	336
	29.9	9.9	19.9	20.0	3.94	385
	29.9	9.9	19.9	20.0	4.10	364
	30.0	9.9	20.0	20.1	4.25	410
	29.9	9.9	19.9	20.0	4.45	389

Strains are relative to zero after hydrostatic consolidation.

* Strains are relative to zero at the start of the final loading cycle and represent creep strains at 100 hour intervals.

8.7.2 Triaxial load test series 410: results and conclusions

The loading phase of the test is similar to that for test 4.1. Pots and gauges show good agreement for axial strain during loading but all gauges failed early during the creep phase of loading.

The creep test is the longest test carried out in the LSTF and shows steady-state creep with little sign of "strain-hardening" over 800 hours between 700 and 1200 hours of testing. The average daily creep is about 250 microstrains/day or 4×10^{-9} /sec.

The test has been conducted with loading manual control and standard 4 men's required every 2 hours or so to maintain the test and continued stress conditions.

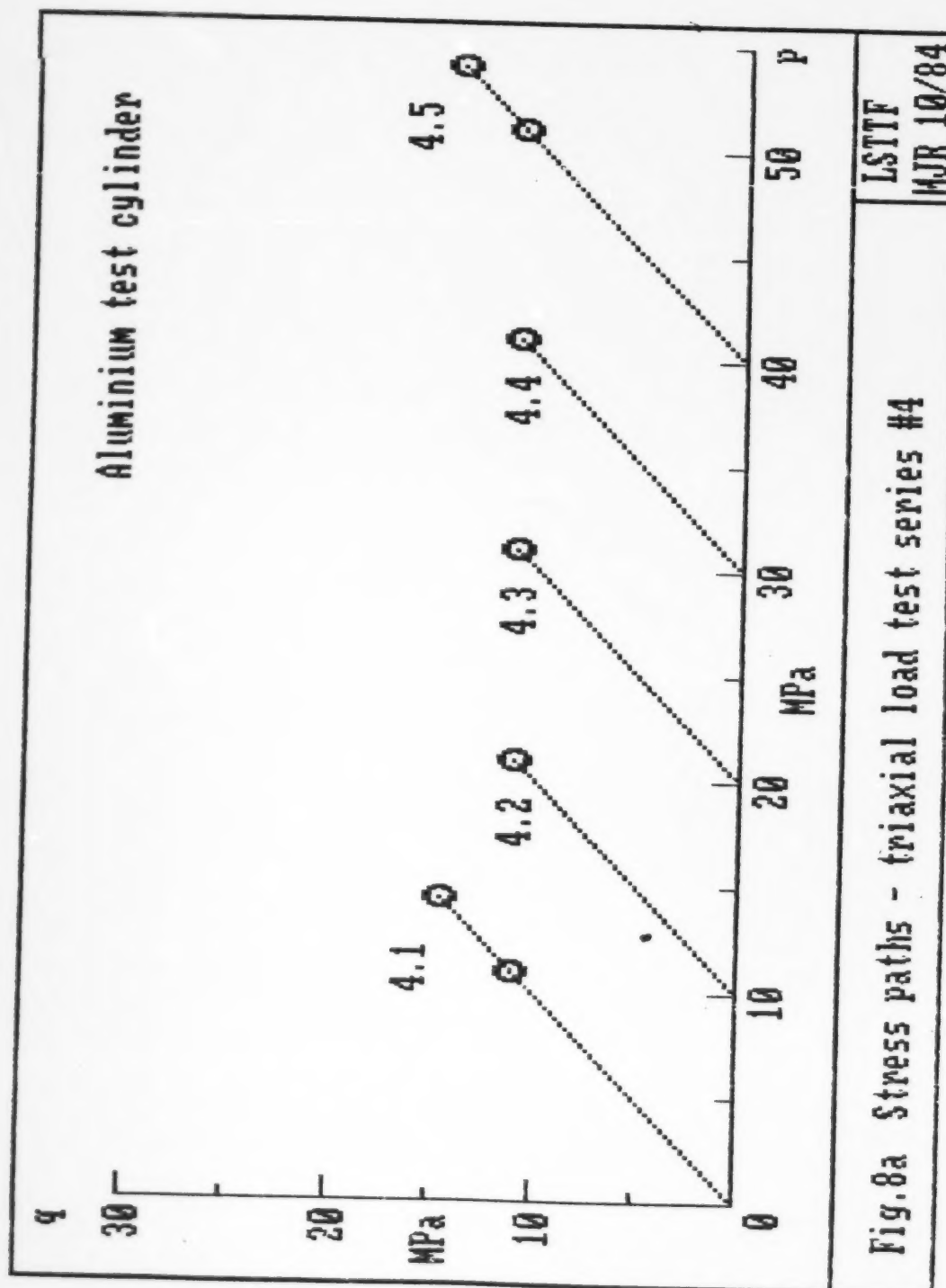
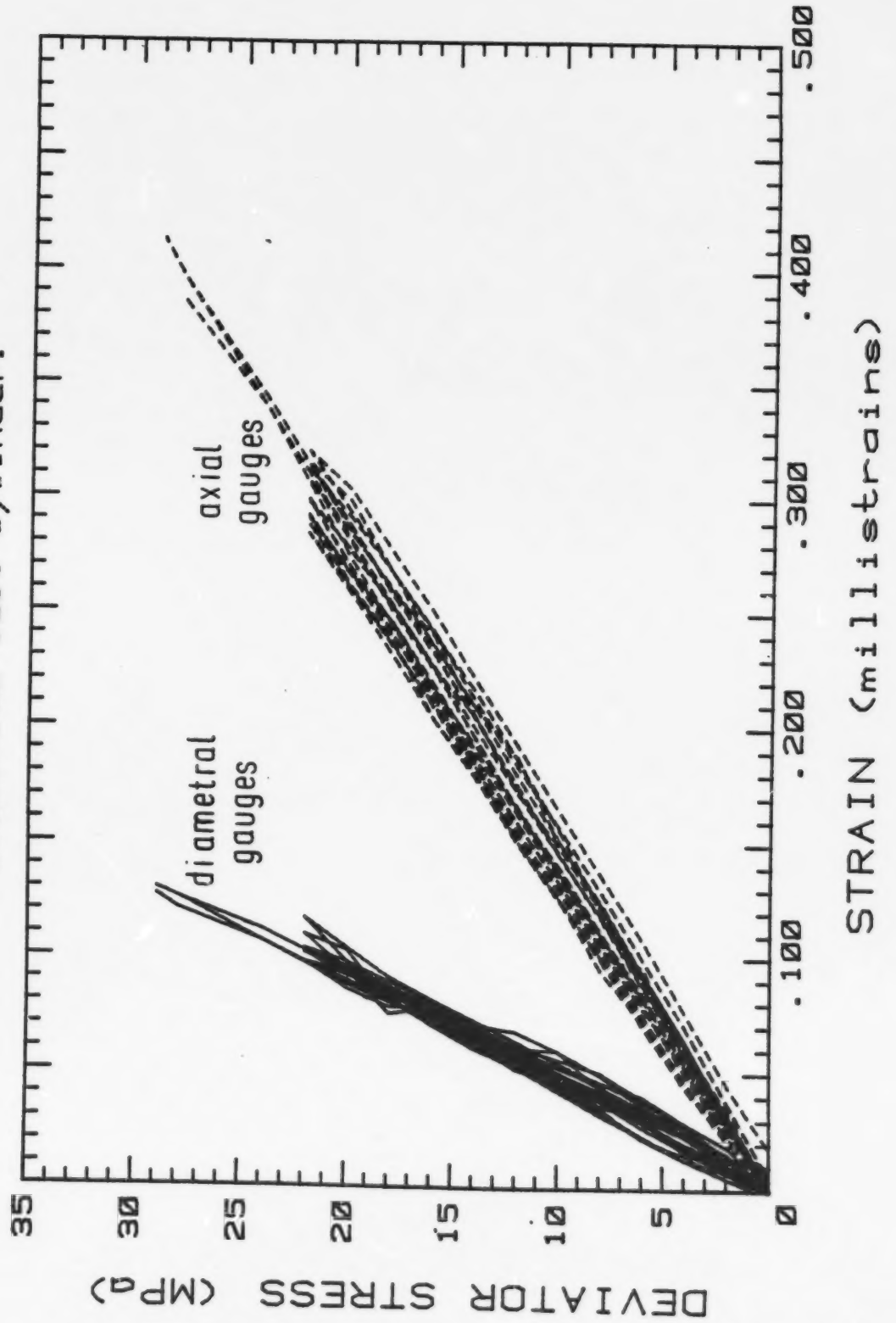


FIG. 8b Stress-strain curves for
triaxial load tests #4.1 - #4.5;
aluminum test cylinder.



Aluminium test cylinder

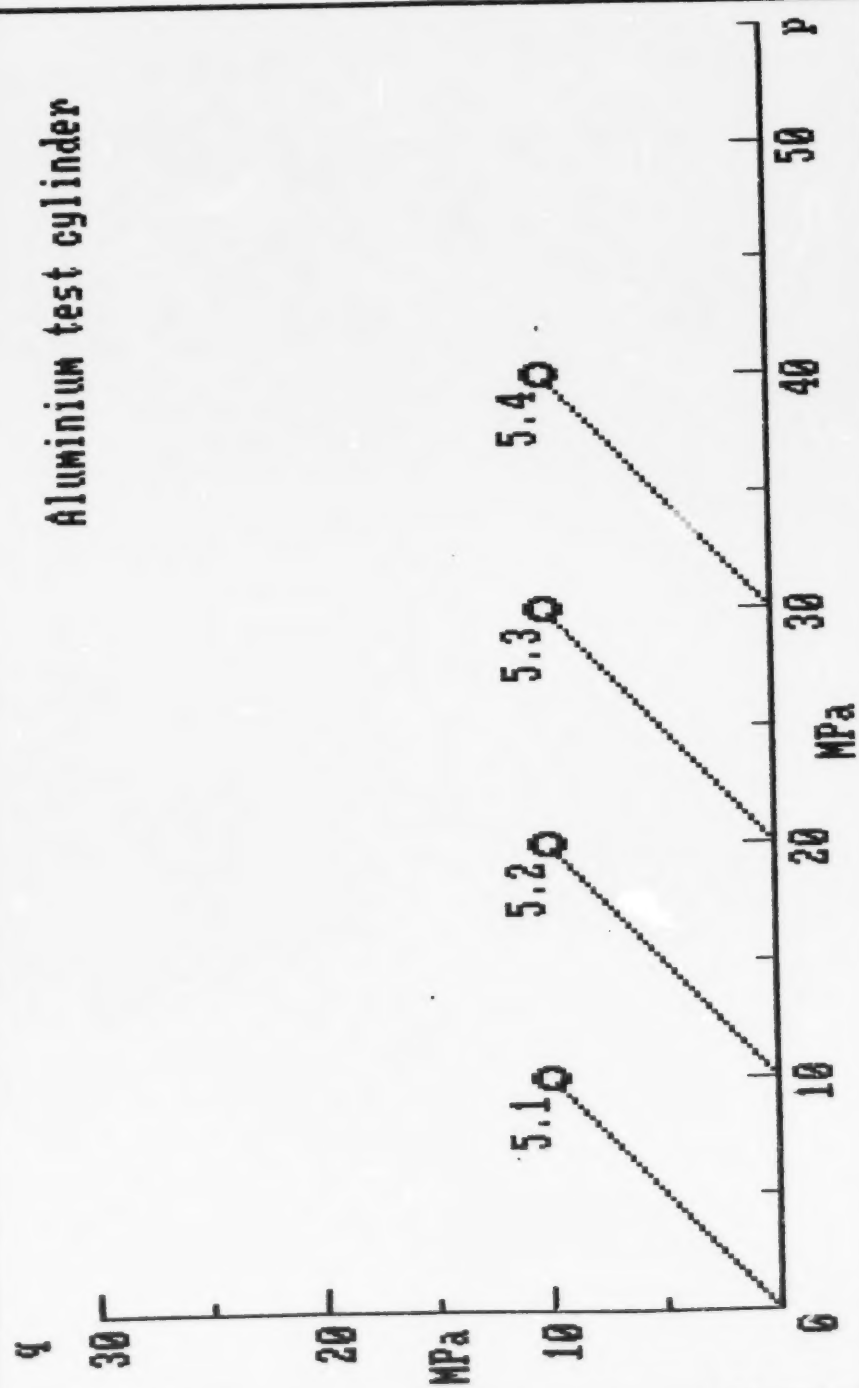
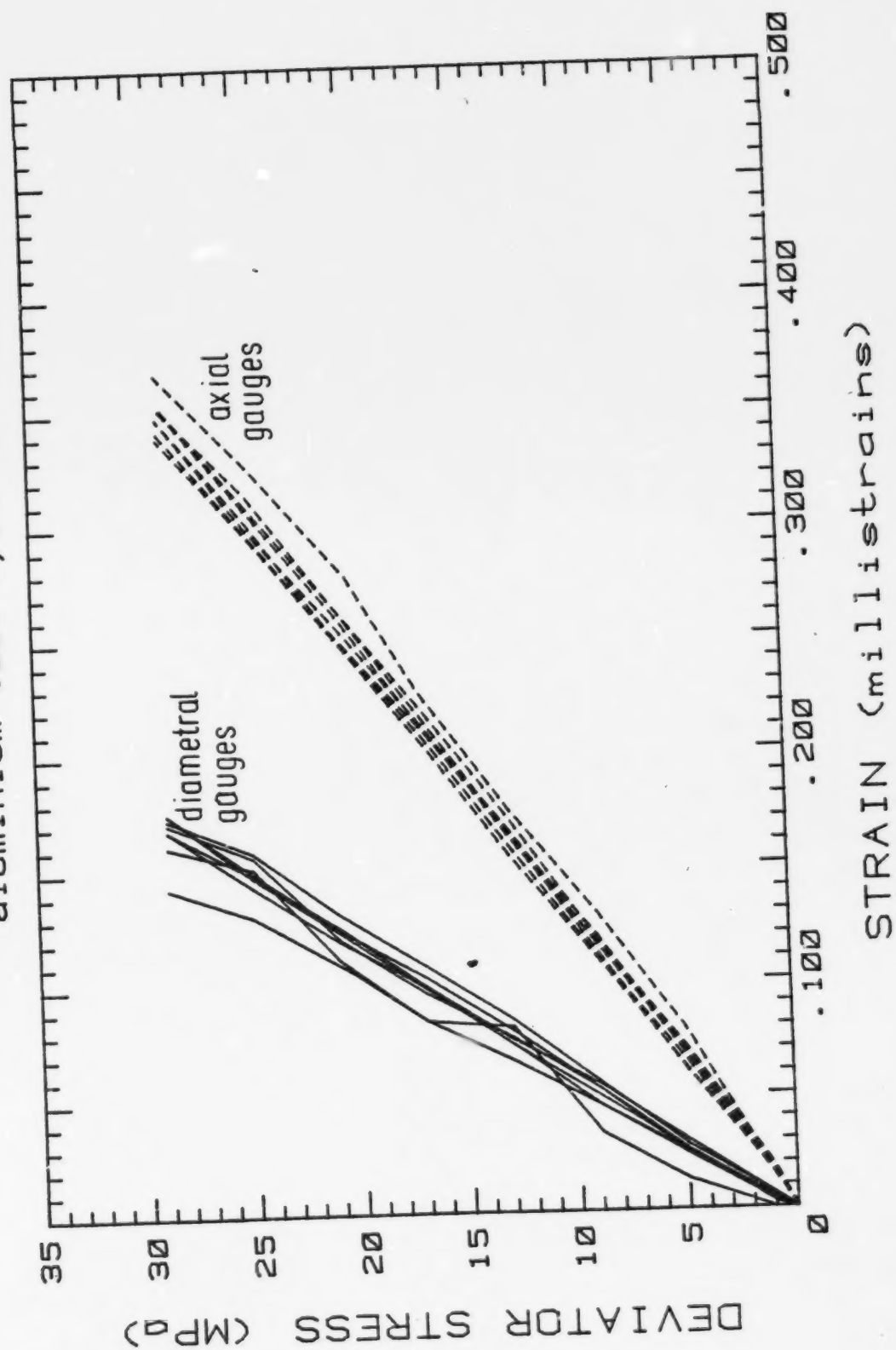


Fig.8c Stress paths - triaxial load test series #5

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FIG. 8d Stress-strain curves for
triaxial load tests #5.1 - #5.4:
aluminum test cylinder.



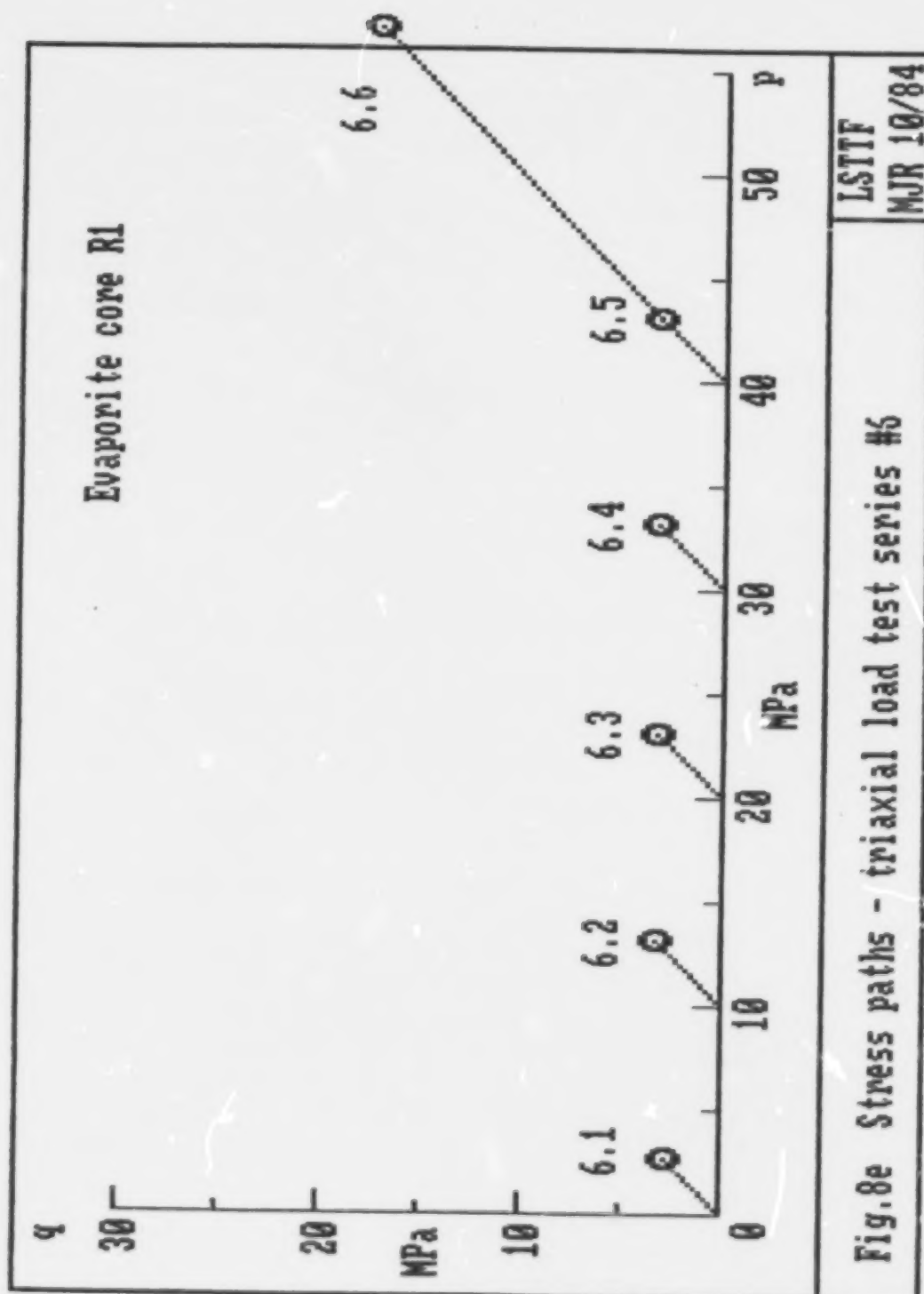


FIG. 8f-a Stress-strain curves for
triaxial load tests #6.1 - #6.5;
potash core R1.

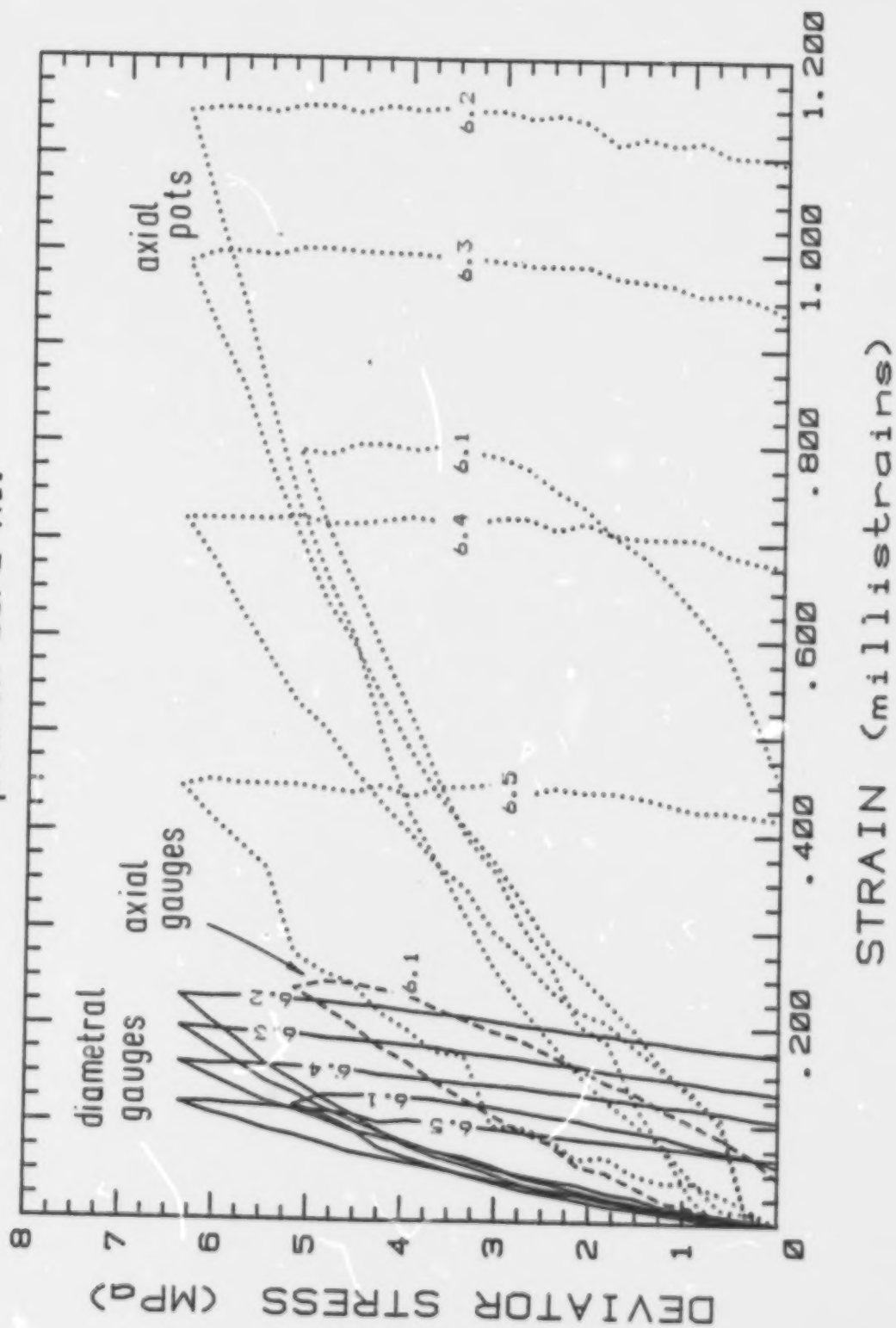
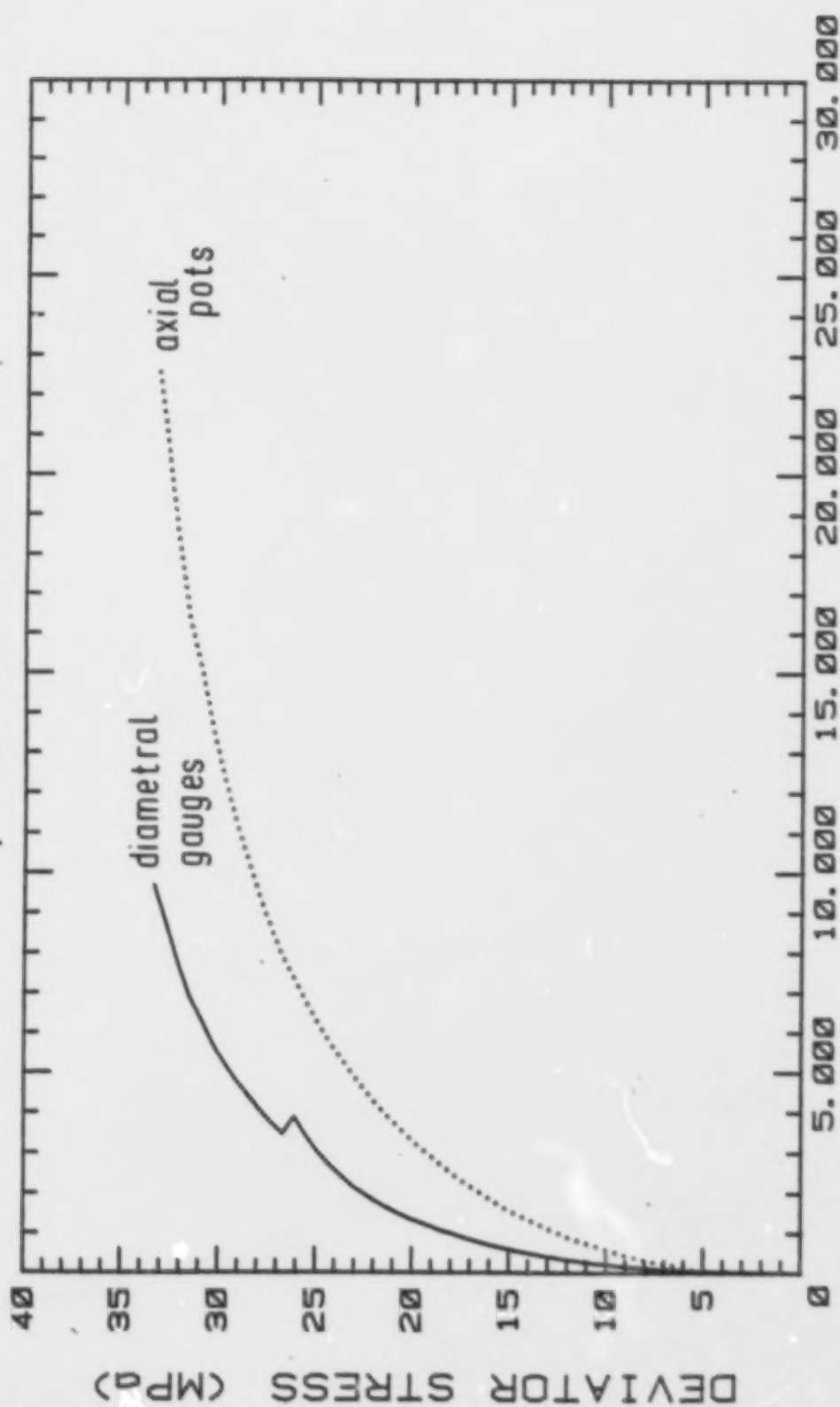


FIG. 8f-b Stress-strain curves for
triaxial load test #6.6;
potash core R1.



STRAIN (millistrains)

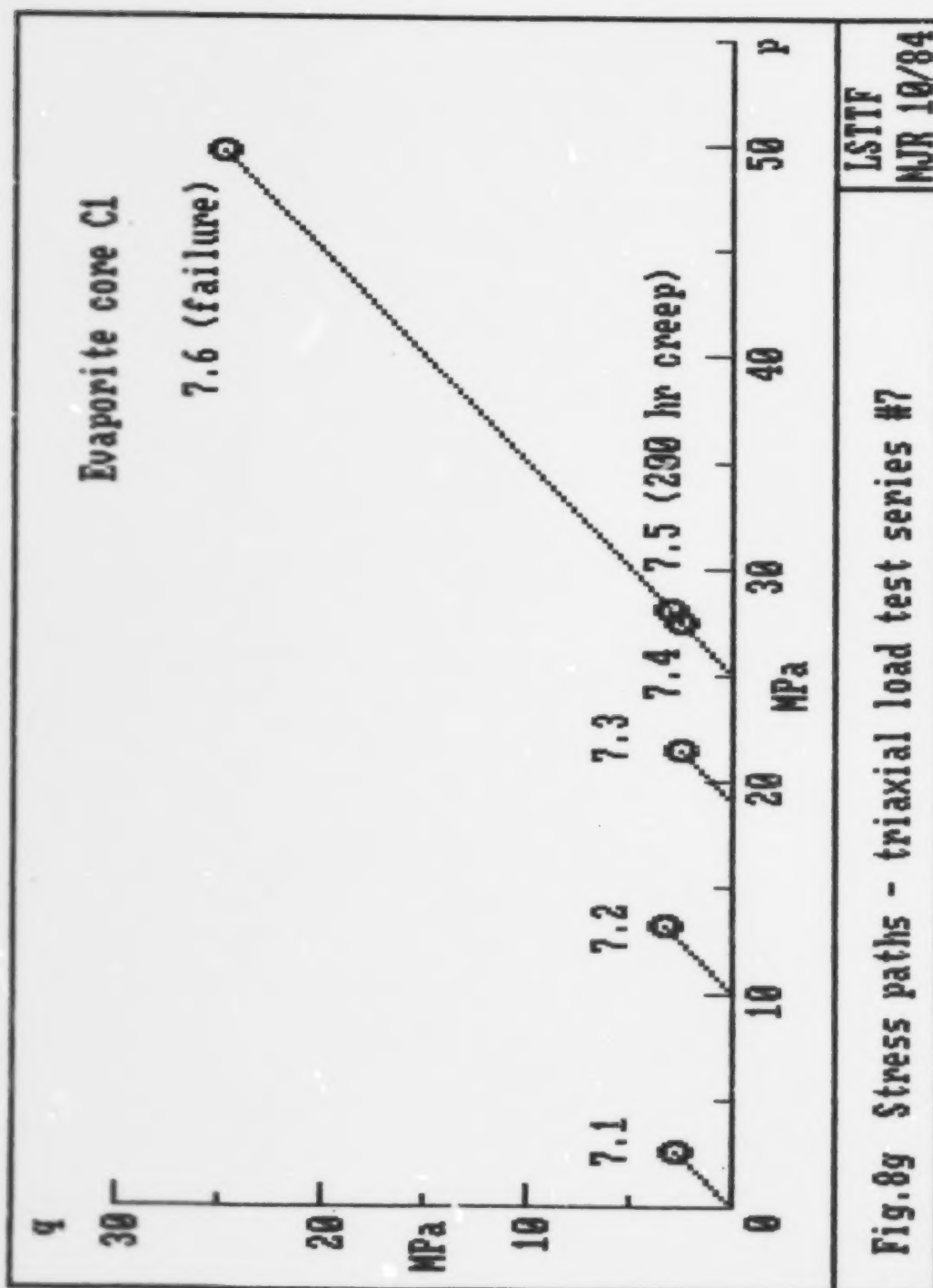


Fig.8g Stress paths - triaxial load test series #7

FIG. 8h-1 Stress-strain curves for
triaxial load tests #7.1 - #7.5:
potash core C1.

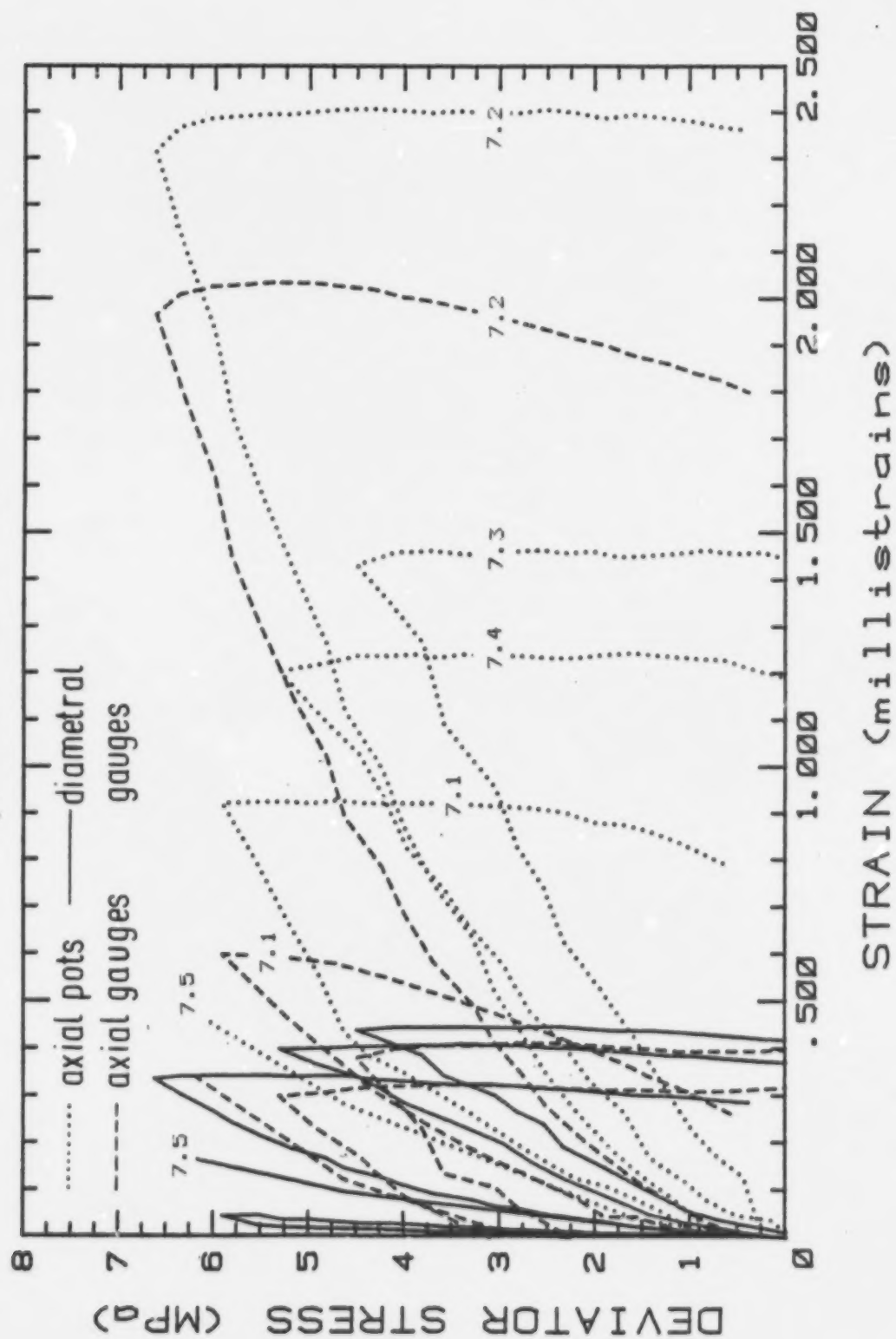


FIG. 8h-2 Stress-strain curves for
triaxial load test #7.6:
potash core C1.

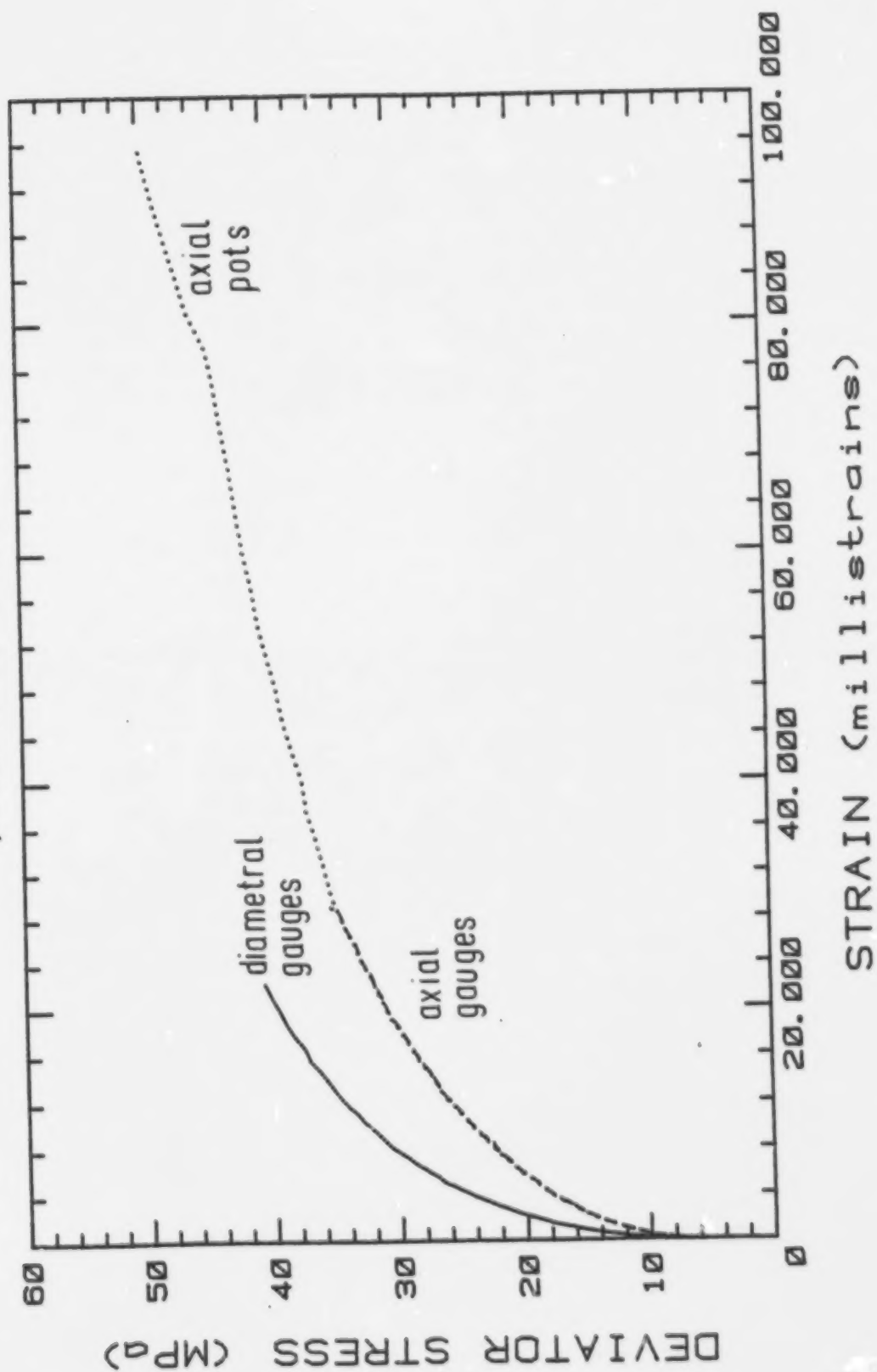
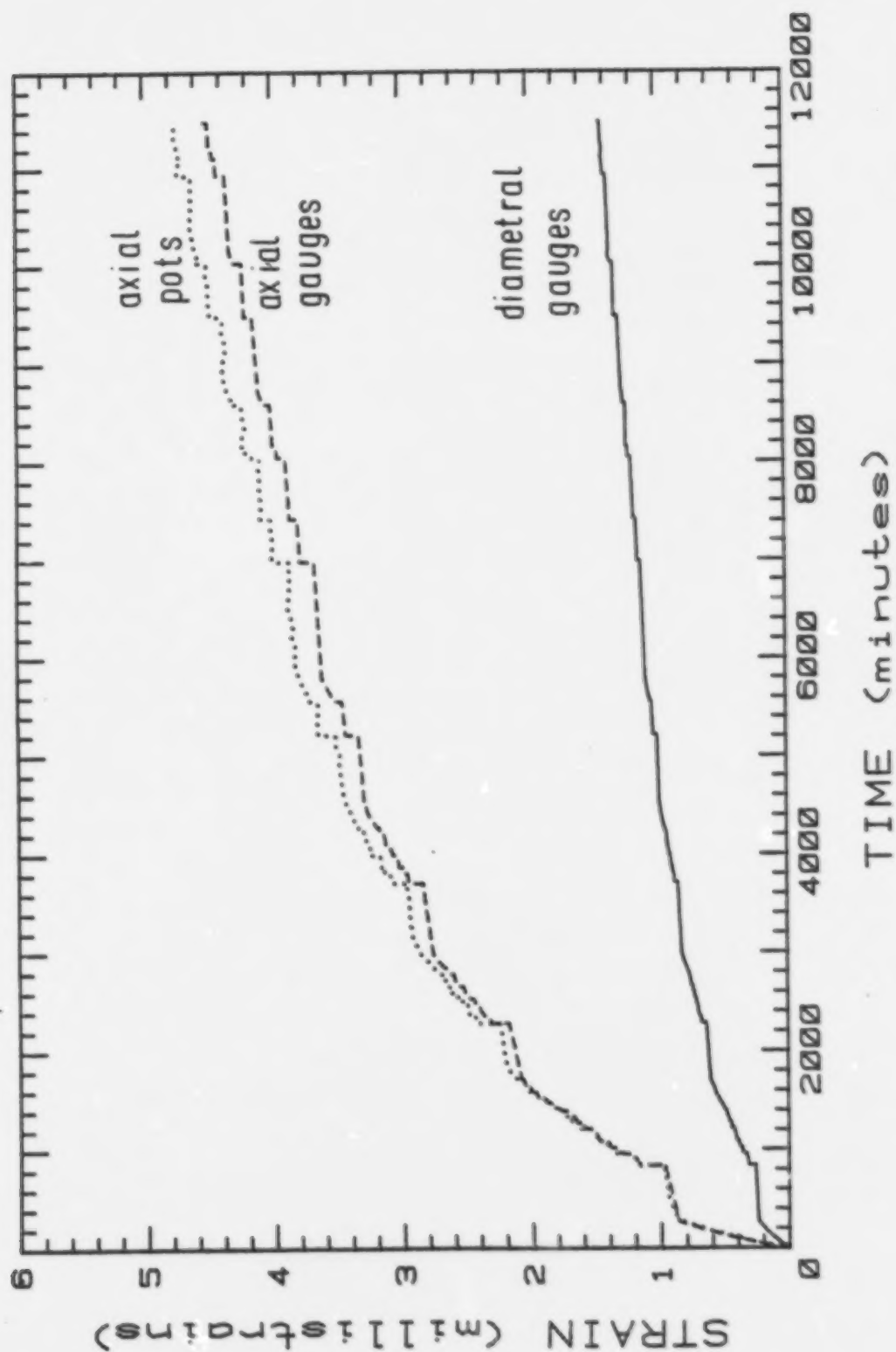


FIG. 81 Strain-time curves for
triaxial creep test #7.5:
potash core C1.



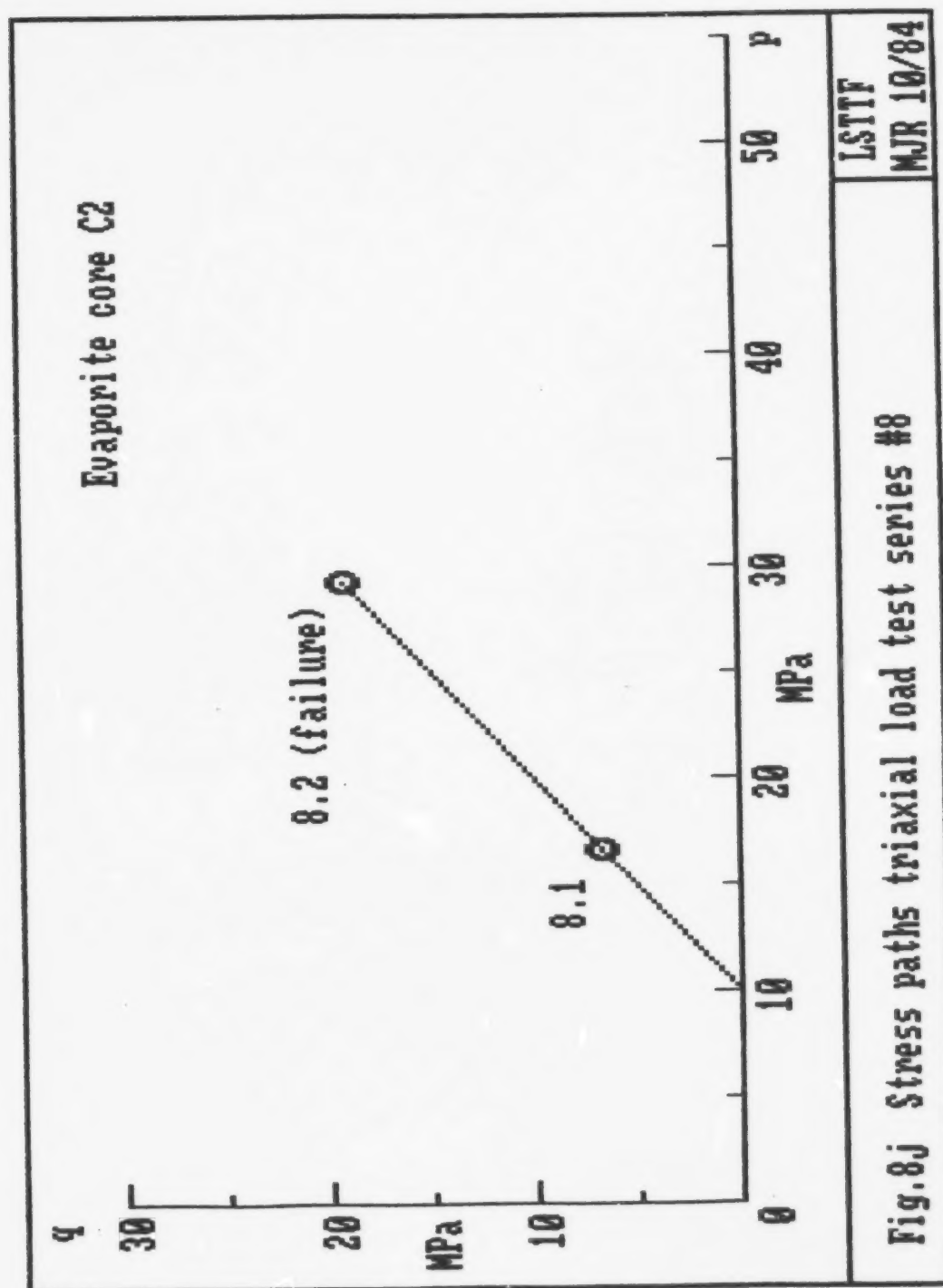
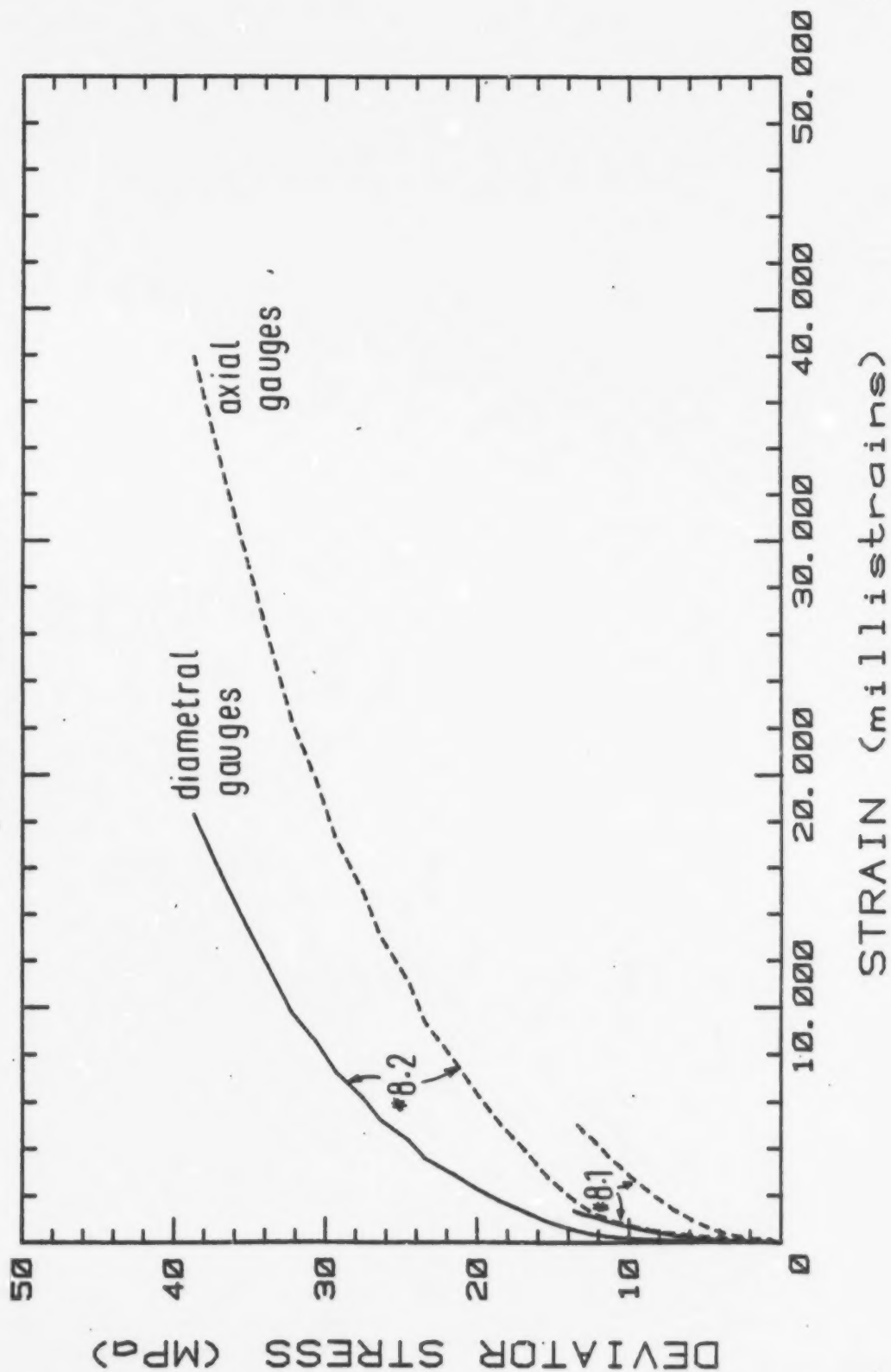


Fig.8j Stress paths triaxial load test series #8

FIG. 8k Stress-strain curves for
triaxial load tests #8.1 - #8.2:
potash core C2.



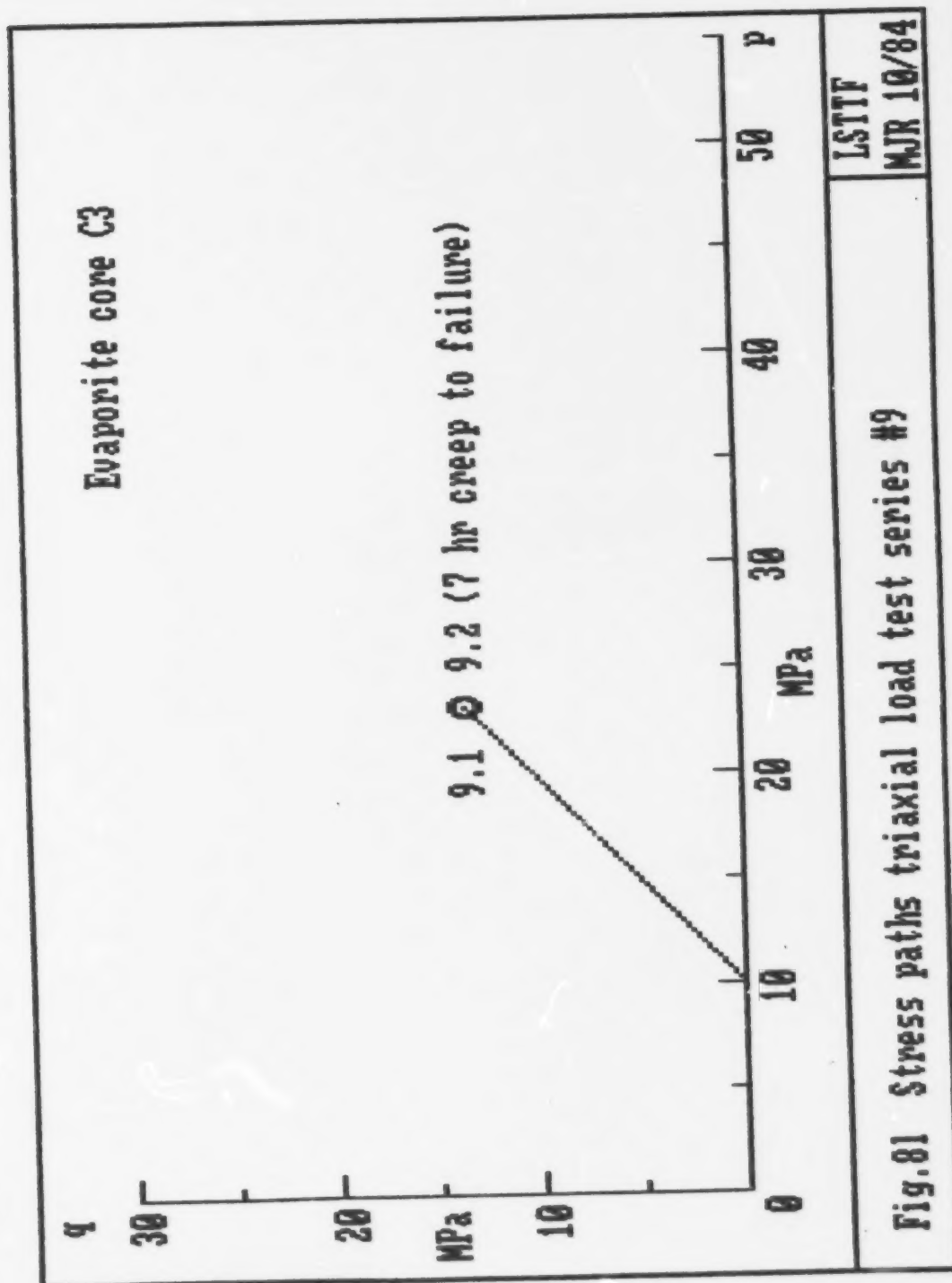


Fig.81 Stress paths triaxial load test series #9

FIG. 8m Stress-strain curves for
triaxial load test #9.1;
potash core C3.

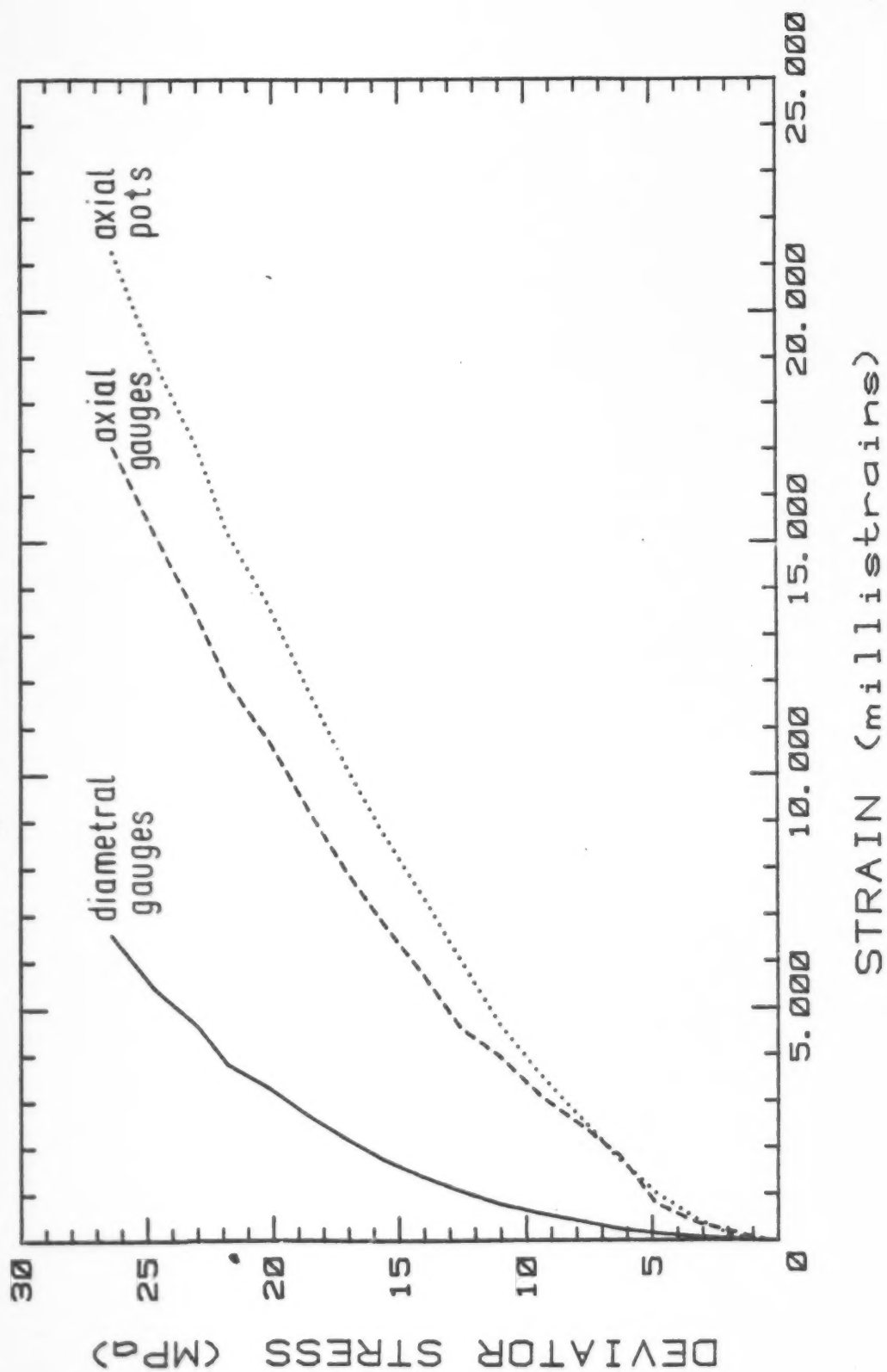
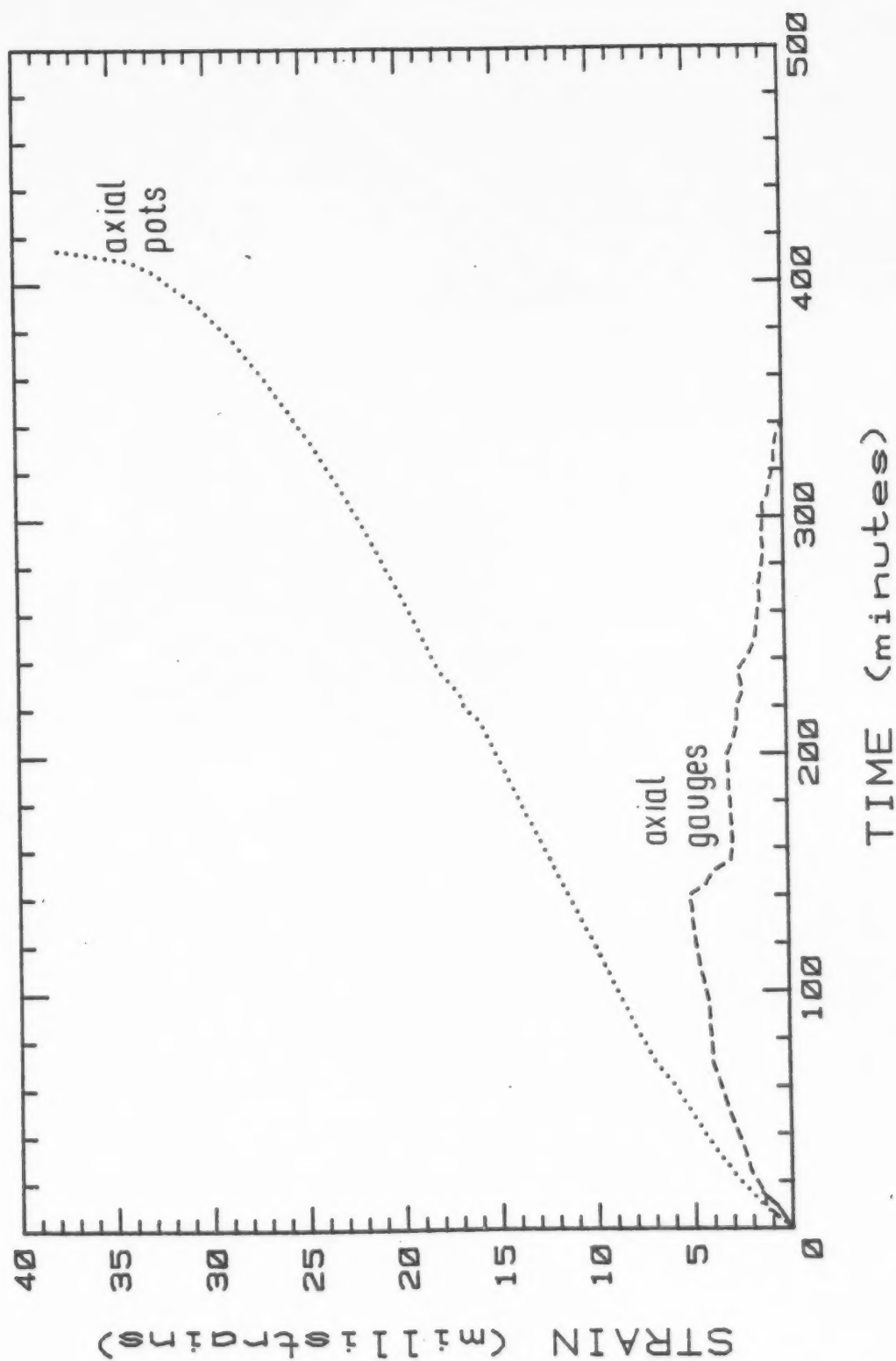


FIG. 8n Strain-time curves for
triaxial creep test #9.1:
potash core C3.



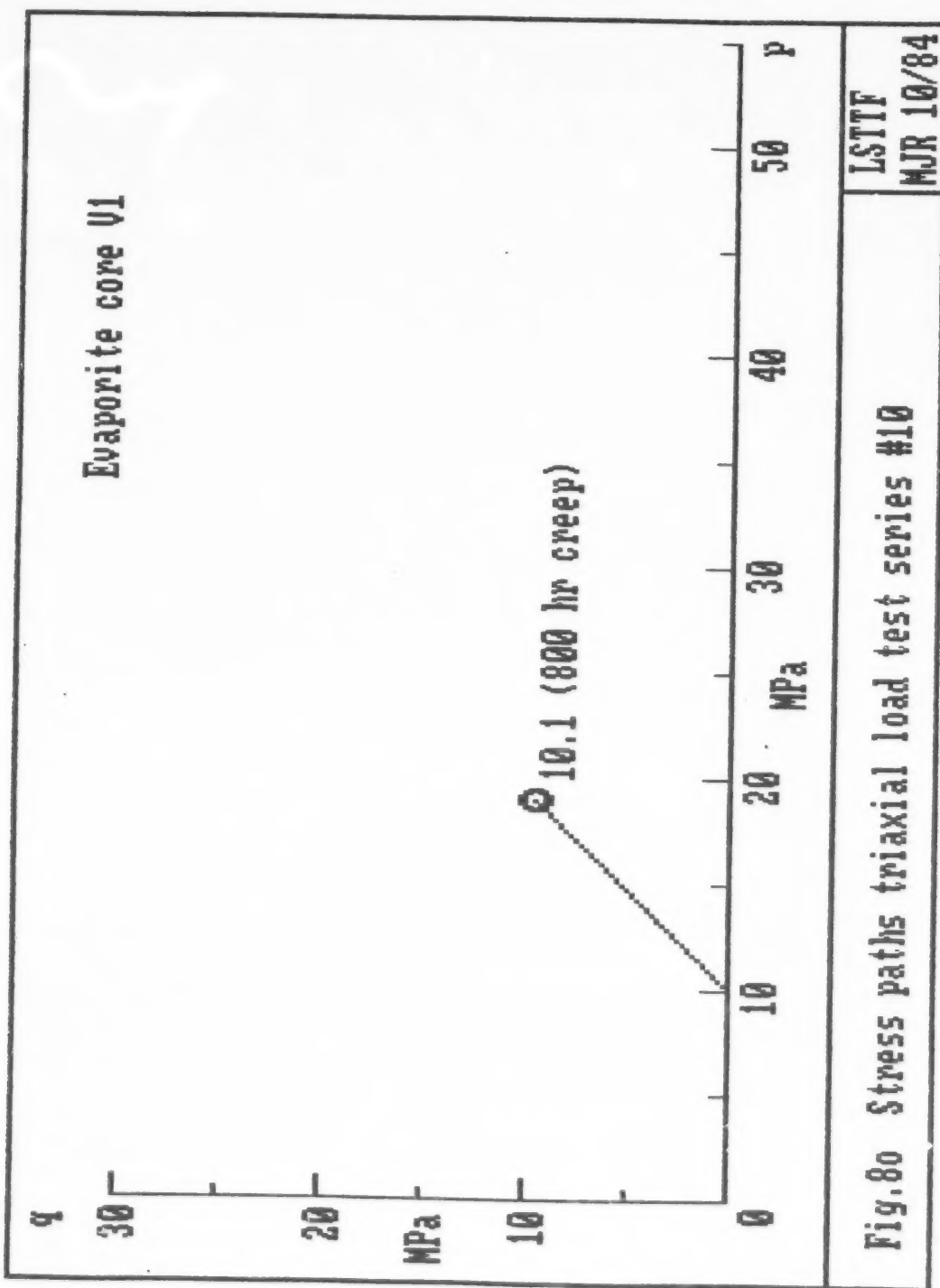


FIG. 8p Stress-strain curve for
triaxial load test #10.1:
potash core V1.

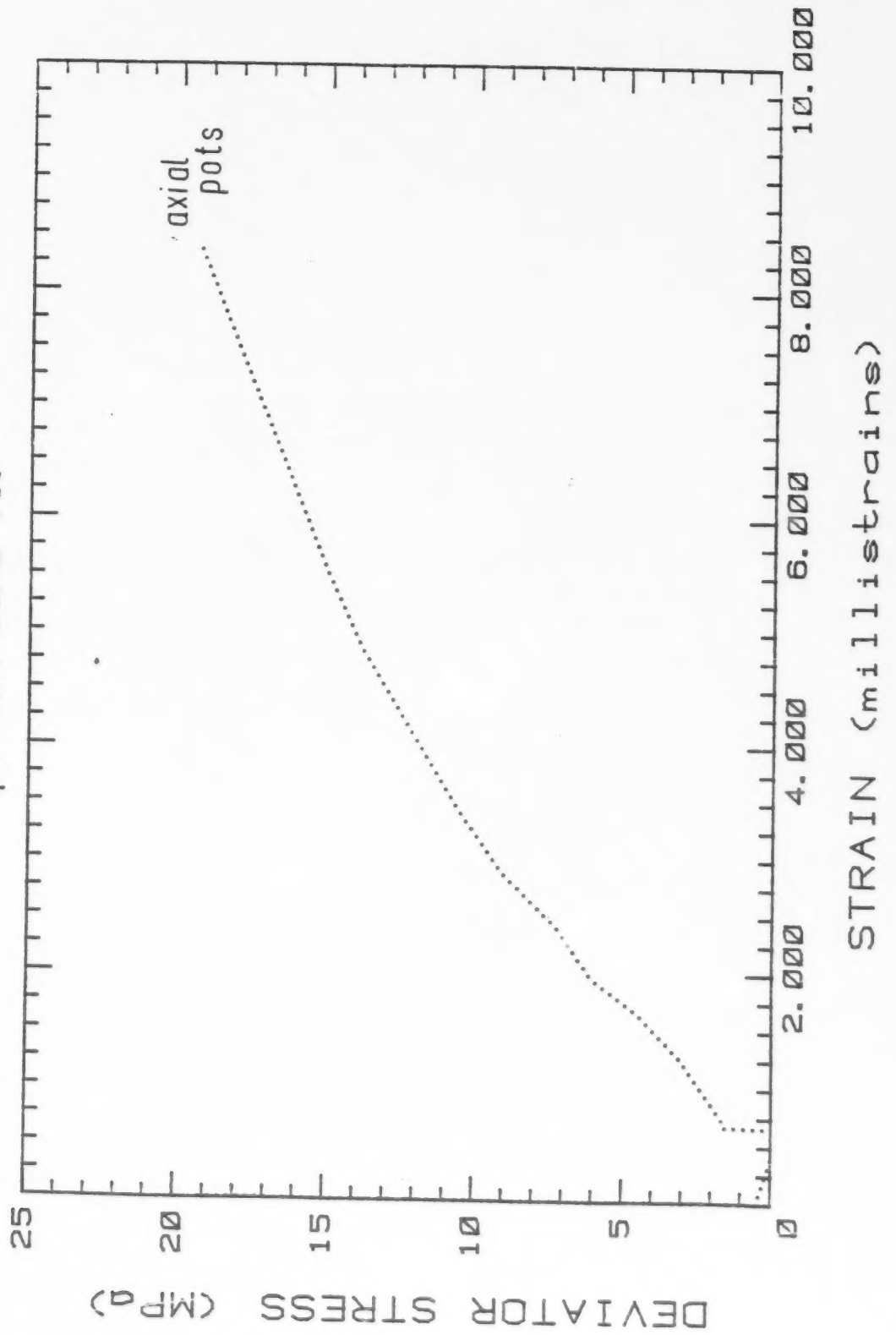
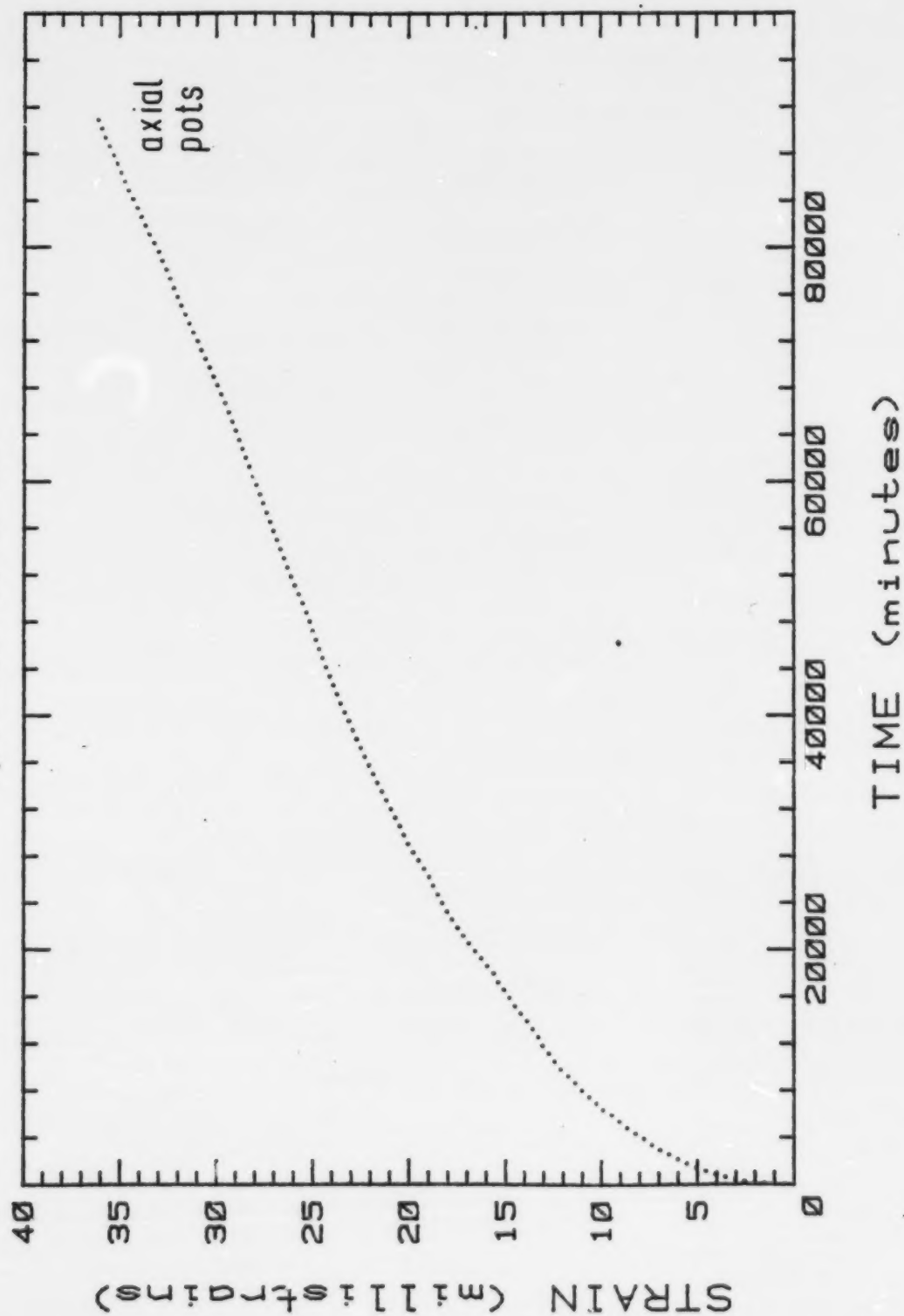


FIG. 8q Strain-time curve for
triaxial creep test #10.1:
potash core V1.



9. COMPUTER LOGGING AND CONTROL

9.1 Power failure protection

For long-term tests, it is important that the system be protected as much as possible from failure of the main power supply. To ensure continuity of supply all laboratory systems may be powered from d.c. batteries through an inverter, the battery being continually charged from the a.c. mains. The d.c. battery supply is filtered to remove any "spikes" before being inverted to power the laboratory.

In the unlikely event of loss of power, all control valves will be closed so that the axial and radial pressures will remain constant (or fall slowly due to minor leaks and creep in the "plumbing" system). It is estimated that a complete loss of power for 6 hours could be tolerated without serious damage to most long-term experiments, providing such a power outage did not occur during the first 6 hours of a test.

The computer control system is programmed to recover from such events but will advise abandonment of tests where vital data have been lost or where the planned test cannot be continued. The default action (without user intervention) is to attempt to salvage the test. All data are "backed-up" on two disks. Data will only be lost if power fails during a "read" operation and then only the current "readings" will be lost. All previous data should be safe.

9.2 Data signals

Data signals are defined as readings from sensors which are logged. All pots, LVDT's, pressure transducers and strain-gauges provide data signals which the computer "reads" or "receives". The acquisition and storage of these signals in digital form is called data logging.

A typical configuration of data sensors involves three axial pots, five horizontal strain gauges and five hydraulic pressure sensing transducers. In some earlier tests, vertical strain-gauges were used as a substitute for, or together with pots. In these circumstances only three horizontal gauges were used. In some cases where computer control was not in operation, pressure transducer readings were not taken since high precision dial gauges gave more sensitive measurements when determining the magnitude of minor leaks in the system.

In the early stages of testing the system this "unintelligent" logging function was carried out using a Fluke data logger. The magnetic tapes written by the logger were subsequently read into the computer for display and analysis.

Later software developments have enabled any serial RS232 compatible logger to be treated as a data sensor or series of sensors so that data collection is not limited by the "on-board" A-D (analogue to digital) capacity.

9.2.1 Data signal conditioning

Most data signals require conditioning (amplification and scaling) before they are read by a logging device. Strain gauge signals are normally in the microvolt range and require the use of a Wheatstone bridge circuit and large amplification (gain) before they can be "read". Pressure transducers and some LVDT's generate signals in the millivolt range and require less amplification. Many of the pots used in the measurements generated d.c. voltages in the range 0 - 4 volts and required no conditioning.

It proved possible with some minor additions and modifications to salvage the original LSTTF (1978) signal conditioning electronics from the Neff logger/controller.

The Tecmar logger/controller card used in an IBM-PC or COMPAQ computer replaces the Neff for all control and logging functions. For signals in the microvolt range, external signal conditioning is required. The Tecmar logger/controller card (TM40-PGH) has 16 channel 12-bit A-D conversion for data acquisition and 24 parallel I/O lines for control. In addition 2 D-A (digital to analogue) output channels are available and a sophisticated set of programmable timer functions can be performed. The most sensitive A-D input range is 1250 millivolts fsd (full scale deflection) which gives a resolution of about 300 microvolts for 12-bit data. Cards with lower level input ranges (TM40-PGL and TM40-PGK) can be obtained but the need to allow amplifiers "settling time" in multiplexed operation means that sampling rates must be sacrificed for increased signal resolution.

With external signal conditioning, the TM40-PGH logger can sample at the rate of 40 kHz (40,000 samples per second). Thus the 16 A-D channels can be read 2500 times per second. It is clear that for the normal range of rock mechanics tests these sampling rates are more than adequate. The ability to acquire data at high rates may become very important if high frequency acoustic emissions are to be monitored ; such emissions are providing valuable information to the potash industry both in the laboratory and in in-situ tests.

9.2.2 Logging software

The software to perform logging functions is very simple. Since fast execution of code is not essential, the programs were written in Microsoft BASICA. For every test 3 (three) files are maintained:

- (a) TEST LOG FILE : is a log of the main events during a test. It records the times of any load changes, sensor failures, power outages or other significant events. It also contains copies of all console messages issued by the automatic logging and control routines. It can be displayed at any time.
- (b) DISK BUFFER FILE : is a small file which is continuously maintained but only used in the event of a restart following a power outage or manual halt in a test. It contains the status of a test when the halt occurred and the information necessary to extrapolate sensor readings for restart.
- (c) TEST DATA FILE : is the main test record file containing all the sensor readings throughout the test. If this file exceeds about half the total disk space the console displays a message which, when acknowledged, causes the old file to be replaced by a new one after back up on the second disk drive. The back-up disk MUST be replaced at this stage.

The software is designed to reject spurious readings and to report any unanticipated readings. At every stage, for every device, an estimate is made of what the next reading will be. The anticipator routines vary depending on the kind of test and the required degree of conformity between anticipated and actual readings can be set by the user. Setting very large tolerances effectively disarms the automatic procedures which would otherwise detect sensor failures.

The interval between readings can be set to a constant value or can be based on the rate of change of sensor signals. This prevents the accumulation of huge amounts of irrelevant data when slow consistent variations are logged.

A memory buffer is used to store data during a read cycle. When data are fully verified, they are written onto the disk buffer file and appended to the main test data file. All files are periodically backed up on a second disk drive; the second disk may be removed or replaced at any stage for permanent storage or transferred to another computer via a serial line.

On restart following a power outage (a very unlikely occurrence) the disk buffer file is used together with the system clock to attempt to salvage the experiment. If the anticipator routines indicate that the loss of control has not seriously compromised the test, an indication of the time and duration of the control is written to the console and the test log file, and logging continues. Otherwise, a warning is issued on the console and written in the test log file. Logging is however continued unless or until the user issues other instructions.

Only if cell pressures are close to operational maxima or control sensors are malfunctioning or no data sensors are working, will an automatic shutdown take place.

9.3 Control signals

Control signals are defined as those "written" or "sent" by the computer to cause some device to operate. The only control signals in the triaxial cell system are five logical open/close instructions to solenoid valves in the hydraulic circuits.

Table 9a indicates the pressures recorded by the 5 transducers which are normally used for control of stresses and strains.

Table 9a : Pressure transducers used for control logic	
Transducer #	Pressure recorded
1	Main accumulator
2,3	Axial pressure circuit
4,5	Radial pressure circuit

Table 9b indicates the connections made by opening the 5 solenoid valves used in the control process.

Table 9b : Solenoid valve connections		
Valve # open	Connection	
1	Main accumulator	Supply line
2	Supply line	Axial pressure circuit
3	Supply line	Radial pressure circuit
4	Axial pressure circuit	Drain line
5	Radial pressure circuit	Drain line

9.3.1 Control signal conditioning

Control signals are the output from the Tecmar controller through an 8-bit parallel port. The signals sent are logic zeros (open) and logic ones (close). The solenoid valves require 110 volts a.c. supply to operate and the switching is achieved through an eight channel opto-isolated power driver card.

A logic zero must be applied to hold the switches open and failure of either the computer or the driver card closes all valves. Up

to eight "mains" switches can be operated so that the three unused lines may be used to drive alarm circuits and/or control the laboratory environment (e.g. temperature, humidity etc).

9.3.2 Control software

The software to operate the control circuitry, in common with the logging software, is relatively simple. It is also written in Microsoft BASICA since the speed of response is not critical.

The routines fall into two distinct groups. Switch routines to open and close switches; and control routines to decide which switches to open or close. The control routines call some simple logging routines for information upon which to base decisions. The control routines are at the heart of the software system and supervise the conduct of the test even if no switching actions are ever necessary.

All switching operations are logged in the test log file but data used by control routines are not always logged. Since the control routines also supervise the logging functions, they save only essential data in the test data file. Operational data are stored temporarily in a memory buffer. All decisions are verified before any switching is performed.

The control routines will attempt to follow the test specification either until pressures in excess of operational maxima are required or until all data sensors indicate values outside preset bounds.

9.4 Data storage/retrieval/display

A series of auxiliary, post-test, processing routines have been written which tabulate and plot various logged parameters or functions of logged parameters.

These routines may be run "on-line" on the computer controlling the test. However they are recommended for use on back-up data disks transferred to another IBM-PC compatible computer. The supervisor program will allow data to be plotted during a test but the user runs the risk of inadvertently "crashing" the system since the console keyboard must be enabled to permit instructions to be entered. In normal control/logging operation a "three-key" operation is necessary to "unlock" the keyboard so that accidental test halts are virtually impossible.

Test data files are printable sequential ASCII files organized in a compact manner for relatively efficient storage/retrieval operations. Packed binary files are not used. The control and logging programs edit the data as they are acquired so that data volumes are relatively small for all but the most complex tests.

Plots can be saved (16K per screen image) to eliminate the necessity for repeated processing of the same data. Stress-strain, stress-time, and strain-time plots are possible for whole or partial datasets. Subset selection is very flexible and time-scales may be made logarithmic or linear.

It is recommended that each individual test with associated plots be saved on its own floppy disk (up to 360K per disk should be adequate in most cases). Additional disks may be necessary if large numbers of plots are required (16K per plot file).

9.5 Software documentation

Final versions of the software will be self-documenting and menu-driven. The BASIC programs comprise many short subroutines.

Line numbers are reserved so that software updates can be "merged" with the existing code. The control/logging package is written in a general form and can be adapted easily for other hardware configurations. The package will log up to 16 analogue inputs and operate up to 8 control devices which accept "on/off type" instructions. Options are available to read data from a RS232 serial attached logger (up to 16 channels) and to send digital output to the computer parallel (printer) port for control. Care has been taken to isolate hardware dependent code so that the software is as transportable as it can be between IBM-PC compatible systems.

The software is continuously under development and test and this description is inevitably outdated. The current version remains a little hardware specific in some areas. A version of the program has been in continuous operation since August 1984. Since this work is not funded by the project, and the LSTTF is one of a number of experiments for which the software is being developed, a detailed account is not included.

Software development is being pursued by Prof. M.J.Reeves at the Department of Geological Sciences in the University of Saskatchewan.

10. RESEARCH APPLICATIONS

10.1 Applications to Energy and Mining research

The Large Sample Triaxial Test Facility (LSTTF) is very versatile in that it is currently capable, or has the potential capability, to carry out a large number of triaxial tests on very large samples (200 mm diameter x 400 mm length). The unique feature of the laboratory is the size of the test specimens that can be handled. The scale dependence of many of the physical properties of rocks and soils is well established and the ability to test large specimens is especially important in :

- (a) fractured rocks and soils,
- (b) coarsely crystalline rocks, and
- (c) coarsely granular tailings and fills.

The second important feature of the LSTTF is its ability to carry out long-term tests under computer control so that the "stress path" for a test may be specified. Triaxial creep, relaxation and consolidation tests may be carried out on large specimens at small stress or strain rates over extended periods of time.

The two capabilities combine to make the LSTTF a very potent research tool in the resource exploitation field.

10.1.1 Evaporite mining applications

The most obvious application is the one for which the laboratory was originally designed; to determine the long-term strength of pillars in coarsely crystalline potash. Plate 10a shows a typical yielding pillar in a Saskatchewan potash mine.

The most important characteristics of potash and rock salt, irrespective of the exact form of any relation between stresses, strains and strain-rates, is that even in the ductile state they retain sufficient "strength" to redistribute stress around an opening. A typical mine opening is shown in Plate 10b.

Data from long-term creep and/or relaxation tests enable this stress redistribution to be reliably predicted and therefore used in the design of extraction methods which ensure both commercial profitability and mine safety.

In some Saskatchewan mines, stress redistribution is a possible cause of frequent microseismic activity and less frequent macro-earthquakes. Stress redistribution may also result in the ingress of water into mines due to tapping of "ancient" water in brine runs; or, more seriously, fracture propagation into overlying saturated brittle rocks. Plate 10c shows a brine seepage in a potash mine caused by pressure concentration around a newly cut entry.

10.1.2 Mine tailings and backfill applications

Many mining operations, including that of potash, generate large volumes of tailings (Plate 10d) which may contain very coarse crystals, particles or fragments. The strength of these materials, when used as fills on the surface or underground, is a critical design parameter. With minor modifications, the LSTTF can perform triaxial consolidation tests on such materials to determine both the rate and ultimate amount of settlement in fills for any design surcharge load. Relatively little experimental work has been carried out on fills with coarse components because facilities to test large samples are rare.

10.1.3 Open pit mining applications

Many open pit mines in Canada are initially cut through glacial deposits. Many of the older tills are heavily fractured and both their strength and drainage characteristics are strongly dependent on the properties of the fracture network as opposed to the intact material. The bulk of rock excavated is also likely to be fractured and jointed.

Tests on small specimens do not sample the fractures and tend to give properties representative of the intact matrix. The LSTTF has the potential to determine strength and drainage characteristics for fractured rock and soil masses on a scale which might reasonably be expected to be representative of both fracture and matrix characteristics.

10.1.4 Heavy oil industry applications

Many of the heavy oil and tar sand deposits of Western Canada are essentially cohesionless soils held together by very high viscosity hydrocarbons. As a result, when attempts are made to produce the oil, there is a tendency for the whole reservoir to "flow" rather than for the oil to flow through the reservoir. Similarly when the tar sands are mined, there is a distinct tendency for the formation to creep (flow).

The LSTTF can determine the creep/flow characteristics over a wide range of triaxial stresses. With a very minor modification (a heater for the hydraulic oil in the radial circuit), the facility can also perform such tests over a range of temperatures from 0 to at least 50 degrees Celsius.



Plate 10a: Collapsed yield pillar in potash.



Plate 10b: Typical mining entries in potash.



Plate 10c: Freshly cut entry with brine seepage.

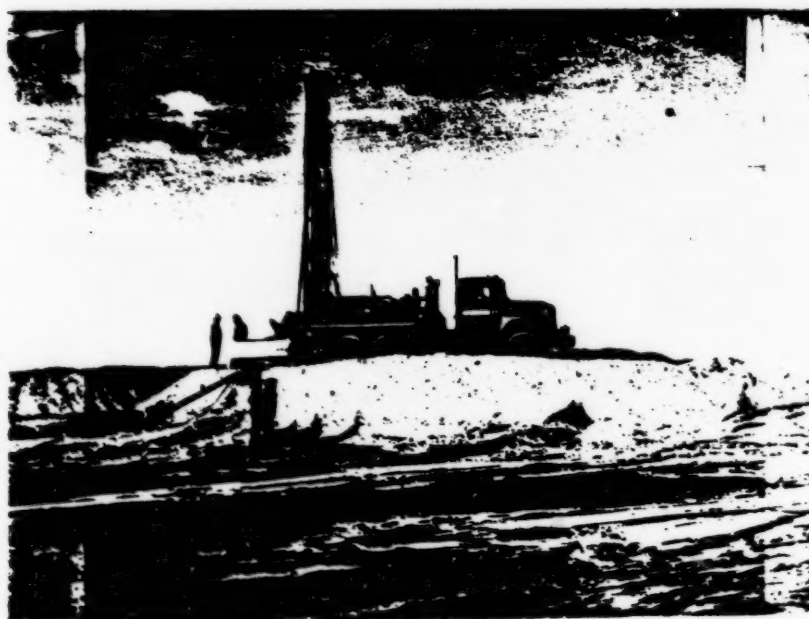


Plate 10d: Rock salt tailings on the surface.

11. CONCLUSIONS AND RECOMMENDATIONS

11.1 Achievement of objectives

The LSTTF evaluation project, funded by CANMET as part of the START programme from November 1983 to June 1984, had three prime objectives :

- (1) To evaluate the triaxial hydraulic loading systems,
- (2) To evaluate the computer control and data acquisition systems,
- (3) To evaluate the facility as a research tool for the resource based industries.

A large number of specific detailed objectives were itemized in section 3. Although not every detailed objective has been precisely met, the three prime objectives have been achieved. The test facility is viable and one of the ten cells is fully operational (and in virtually continuous operation).

11.2 Current capabilities of laboratory

The LSTTF has one fully controlled pressure cell in operation. Much of the equipment used to put the facility into operation, however, has been "borrowed" from other projects and thus an injection of capital is necessary to operate the facility independently.

Considerable technical and scientific expertise has been developed during the life of the project, but all staff involved with the project have full-time employment elsewhere and the laboratory is operated on a part-time basis as a research interest.

The current status of the laboratory is summarized in Table 11a. The derivation of the numerical values in the Table can be found in sections 6 to 10.

It costs a considerable amount to carry out any kind of test in the LSTTF.

Costs for sample installation and removal are the least flexible and attempts to "cut corners" in this area have been found, by experience, to result in damage to sample, sensors or wiring. It is then necessary to remove the sample and repeat the lengthy assembly procedure. The design of the building and the pressure vessels largely predetermine the loading/unloading time.

Sample preparation costs depend on the treatment specified for sample ends. Parallel facing, grinding, lapping and use of lubricants on platens all involve additional time and cost which may or may not be justified.

Instrumentation is also a very variable cost item. All sensors require time for attachment and wiring. Disposable sensors (strain gauges) are a particularly large cost item. Development of a "re-usable" girth monitor or a technique to accurately predict oil-volume may help to provide more data at little extra cost, but it will not reduce the minimum time required for attachment and wiring.

Table 11a : LSTTF status as of 1 July 1984

Maximum confining stress	50	MPa
Maximum uniaxial stress	225	MPa
Maximum axial stress at 10 MPa confining	190	MPa
Maximum axial stress at 20 MPa confining	155	MPa
Maximum axial stress at 30 MPa confining	120	MPa
Maximum axial stress at 40 MPa confining	95	MPa
Maximum axial stress at 50 MPa confining	50	MPa
Pressure transducer precision	+/- .07	MPa
Pressure transducer accuracy	+/- .40	MPa
Maximum axial strain	15	%
Maximum radial strain	15	%
Linear potentiometer precision	+/- 9	microstrains*
Linear potentiometer accuracy	+/- 20	microstrains
Strain gauge precision	+/- 1	microstrains
Strain gauge accuracy	+/- 5	microstrains
Maximum relaxation rate	> .2	MPa/sec
Maximum creep rate	125	millistrains/sec*
Minimum stress increment	+/- .1	MPa
Pore pressure control		Not Available
Laboratory temperature control	+/- 1	Celsius
Minimum cell temperature		Ambient
Maximum cell temperature	> 30	Celsius
Cell temperature control		Not Available
Maximum logging rate	> 25	Hz (channels/sec)
Maximum control instruction rate	> 2	Hz (/sec)
Preparation time	> 2	man hours
Instrumentation costs	> 4	man hours
Installation/removal costs	> 32	man hours
Daily supervision/logging/control costs	< 1	man hour

* A microstrain (μS) is one micron per metre. A millistrain (MS or ms) is one millimetre per metre.

11.3 Proposals for further research and development

The current phase of work has served to reveal the huge potential of the LSTTF as a research tool. A single cell is now operational on a research basis but additional capital equipment and further development is necessary before the laboratory can undertake a substantial test program.

The major requirements are :

- (1) Employment of a full-time laboratory technician responsible for the day to day maintenance and operation of the facility.
- (2) Purchase of a computer logger/controller system dedicated to the facility.
- (3) Further software development to operate more than a single cell and extensive reliability trials for the current control/logging software (which is essentially untested).
- (4) Purchase of a high volume accumulator rated to 70 MPa with capacity to run up to 5 cells.
- (5) Commissioning of 2 additional cells to incorporate the modifications made on the first research cell.
- (6) Modifications to enable control of cell temperature and measurement and control of pore fluid pressures.

11.3.1 Development of triaxial cells and hydraulics systems

The modifications recommended for the hydraulic cells are relatively minor changes to the "plumbing" system involving rearrangement of existing pressure sensors and control valves.

The small hydraulic accumulators in the original design have insufficient volume and pressure ratings to operate successfully. Rather than replace all 10 small accumulators, it is recommended that two banks of 5 cells be operated from two independent large accumulators with a maximum pressure rating of 70 MPa. The 5 cells will share a common manifold line.

The logger/controller is capable of operating adequately without individual accumulators since a single manifold charge only is required for each cell adjustment if the independent bleed lines are used for "fine-tuning".

It is recommended that the upper (non-levelling) platens be tapped to enable the measurement and control of pore fluid pressures. Use of the sensors and control valves salvaged by the elimination of the small accumulators would enable this modification to be made at minimal cost in terms of new equipment. Provision of 200 mm diameter porous plates should not be enormously costly and not all cells need be so equipped. Pore pressure measurement enables the control of effective stresses during testing and extends the range of the LSTTF to include triaxial consolidation and permeability tests.

It is recommended that a number of cells be fitted with heating

coils capable of raising the hydraulic oil temperature to at least 50 degrees Celsius. Such a modification would cost relatively little and add enormously to the scope of the test facility. Tests should be performed to determine whether heating the oil in the radial circuit alone provides adequate control.

11.3.2 Development of instrumentation for deformations

The currently developed system of strain measurements is to use vertical pots and horizontal strain gauges for most tests. For relaxation tests, vertical strain gauges are preferred since they give additional sensitivity when trying to maintain controlled levels of strain.

The linear potentiometers work well under high pressure oil-immersion conditions but have rather low accuracy (about ± 20 microstrains). Alternative linear voltage displacement transformers may be purchased to increase the accuracy of vertical strain measurement. LVDT's for such an application are only available on a "custom" basis and are likely to be very expensive and unproven. It is recommended that cells be fitted with one LVDT accurate to ± 5 microstrains and two potentiometers as backup. This represents a modest cost and will permit the evaluation of LVDT performance.

Experiments are proceeding at GELUS using thin, flexible, semi-cylindrical, stainless-steel plates (with strain-gauges attached) between the test specimen and the "ecosil" jacket. Preliminary results on 100 mm diameter specimens are promising and the devices may even prove re-usable. Trials are proceeding on small specimens because of the high costs of precision machining of stainless-steel. Various "wire-wrap" resistance devices are also under consideration.

It is possible in theory to estimate the volume of oil entering or leaving the cell in the radial circuit using the differential pressure and the time for which the solenoid valve is open. It is also possible to estimate the slow "leakage" rate for each cell. Since the computer has all these data, an independent estimate of volumetric strain can be made. Since all cells and all valves are slightly different, the use of this indirect technique requires calibration. Experiments are in progress to use this method to back-up the direct measurements. This work was originally scheduled at an early stage in the project but was not possible because of the failure of the original Neff controller electronics and the consequent delay in designing and installing suitable replacement systems.

11.3.3 Development of computer logging and control systems

The development of control systems for the LSTTF lagged a long way behind schedule because of the Neff controller (assumed to be

available at the outset of the project) was found to be unserviceable. The replacement system only became fully operational in June 1984 so that little testing of the control hardware or software was possible during the life of the project.

Additional work in the month of July has established the viability of the control system more fully. Eight control switches and 16 A-D channels per cell seem adequate for most purposes and signal conditioning electronics for both data and control lines can be provided for about \$1000 per cell.

The IBM-PC computer used to control the system is capable of controlling all ten cells. However, it is recommended that cells be independently controlled in banks of no more than 5 with individual computers running the same software. This is both consistent with the recommendation to use two pressure accumulators and in addition, guards against complete disabling of the laboratory by a single computer failure.

The necessity to acquire data from an independent logger on a serial line during the development indicated a number of advantages. It is recommended that the possibility of using logging units connected via RS232 serial lines be investigated. Although this limits the speed with which data can be acquired, it gives added flexibility and enables both software and hardware to be more widely utilized.

The cost of the IBM-PC computer to run 5 cells with appropriate logger-controllers is approximately \$7500 or \$1500 per cell (additional to the \$1000 signal conditioning).



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The work was carried out by Z.Szczepanik (U of S) and J.Jones (SRC) under the supervision of Dr M.J.Reeves (U of S) and Dr R.G. Arnold (SRC).

Advice and assistance in obtaining suitable material for testing was provided by PCS and Cominco. Without the support and co-operation of these and other mine operators in Saskatchewan, the research could not have been undertaken and their contribution is gratefully acknowledged.

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APPENDIX I - SCHEDULE OF WORK

I.1 Original schedule

The original test schedule and work schedule is given in Table 1a. As the work proceeded various modifications to this schedule became necessary in order to meet the aims and objectives as outlined. The main modifications were made necessary by delays in obtaining equipment and supplies necessary to implement the computer control functions. Premature failure of samples in intended "long-term" creep/relaxation tests also resulted in schedule modifications.

Table 1a : LSTTF cell evaluation - proposed schedule of work.

Item in contract statement of work

1. Make necessary repairs and replacements to original equipment to enable the execution of "long-term" triaxial creep tests.
 2. Instrumentation of aluminium test cylinder to act as a "load cell" for calibration purposes.
 3. Acquisition of sufficient evaporite (potash) test specimens for 18 individual tests (with the assistance of PCS).
 4. Mineralogical description of typical evaporite test specimens.
 5. Preparation and appropriate instrumentation of evaporite test specimens.
 6. CALIBRATION TEST SERIES to calibrate the axial hydraulic loading system using both the aluminium test cylinder ("load cell") and evaporite cores.
 7. Development of computer control functions in response to both radial and axial pressures (including "fail-safe" shutdown).
 8. PRESSURE TEST SERIES to determine the extent of pressure losses over a range of pressures up to the maximum operating pressure of the system.
 9. Development of computer logging functions for pressure transducers, potentiometers, LVDT's and resistance wire strain gauges. Development of software to store, retrieve, plot and display data so acquired.
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10. PRESSURE TEST SERIES to determine the number and frequency of manual pressure adjustments necessary to maintain constant axial and/or radial cell pressure over an extended period of time (up to 7 days) at pressures up to the maximum operating pressure of the system.
 11. PRESSURE TEST SERIES to prove pressure control procedures under computer control.
 12. TRIAXIAL LOAD TEST SERIES to check axial load transfer efficiency, axial piston friction and "evenness" of loading over the operational range of radial and axial pressures using the instrumented aluminium test cylinder with computer data logging.
 13. efficiency, axial piston friction and "evenness" of loading over the operational range of radial and axial pressures using the instrumented aluminium test cylinder with computer data logging.
 14. over the operational range of radial and axial pressures using the instrumented aluminium test cylinder with computer data logging.
 15. Development of computer logging functions for volumetric and diametral strain.
 16. TRIAXIAL LOAD TEST SERIES to carry out controlled strain-rate tests using the instrumented aluminium test cylinder over the operational range of radial and axial pressures with computer data logging.
 17. During all tests check for "evenness" of loading for evaporite test specimens with non-parallel faces.
 18. Development of computer control software to perform conventional constant load creep tests (constant axial and radial pressures) and creep tests at any specified value of volumetric strain (continuous adjustment of axial and radial pressures).
 19. TRIAXIAL LOAD TEST SERIES to carry out incremental load tests followed by creep tests at the final load on evaporite test specimens over the operational range of radial pressures with computer data logging.
 20. TRIAXIAL LOAD TEST SERIES to carry out controlled strain-rate load tests followed by extended creep/relaxation tests on evaporite test specimens with computer data logging.
-

Table Ia is essentially a paraphrase of the contract statement of work. The item numbers 1-20 correspond to those used in the contract. Item 14 in the original document implicitly includes 12 and 13 so that separate entries in Table Ia are unnecessary.

Each test series comprises 3 to 5 tests as specified in the contract document. Many of the earlier test series were devised to evaluate the equipment response rather than that of the test specimen. They therefore employ the same test specimen repeatedly since considerable time and expense is involved in the preparation,

instrumentation and installation and removal of the specimens from the triaxial cells.

In the later test series, which were essentially multi-stage evaporite material property tests, much greater care was taken in specimen preparation although these tests were conceived more to evaluate the data logging and control systems rather than to document evaporite properties.

Although the actual schedule of work differs in detail from that originally proposed, the original aims and objectives were largely met.

1.2 Report organization

Table Ia does not provide particularly useful headings under which to discuss the actual work programme nor is it ordered conveniently. Table Ib gives the main items to be discussed in this report in the order they will appear. In order to identify items from Table Ia with the appropriate report heading, Table Ib cross-references the items in Table Ia.

Table Ib : Report organization.

Principal Heading	Cross-reference Table Ia
1. ABSTRACT	
2. INTRODUCTION	
3. OBJECTIVES	
4. EQUIPMENT DESCRIPTION	[1]
5. TEST SPECIMENS	[2][3][4][5]
6. CALIBRATION TESTS	[6]
7. PRESSURE TESTS	[8][10][11][17]
8. TRIAXIAL LOAD TESTS	[12][14][16][17][19][20]
9. COMPUTER DATA LOGGING AND CONTROL	[7][9][13][15][18]
10. RESEARCH APPLICATIONS	
11. CONCLUSIONS AND RECOMMENDATIONS	



TABLE IIa LOAD TEST #6.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	GAUGE
					ms	ms	ms	ms
0	20.5	0.0	0.0	0.0	0.000	0.000	0.000	0.000
3	20.5	.3	0.0	.3	.004	.004	0.000	.004
6	20.5	.6	0.0	.6	.004	.007	0.000	.007
9	20.5	.9	0.0	.9	.026	.016	.006	.005
12	20.5	1.2	0.0	1.2	.077	.022	.010	.003
15	20.5	1.5	0.0	1.5	.123	.037	.014	.010
18	20.5	1.8	0.0	1.8	.186	.051	.017	.017
21	20.5	2.1	0.0	2.1	.203	.058	.023	.013
24	20.5	2.4	0.0	2.4	.265	.082	.028	.027
27	20.5	2.7	0.0	2.7	.305	.094	.033	.029
30	20.5	3.0	0.0	3.0	.361	.109	.040	.029
33	20.6	3.3	0.0	3.3	.396	.125	.048	.030
36	20.5	3.6	0.0	3.6	.453	.142	.057	.029
39	20.5	3.9	0.0	3.9	.521	.163	.065	.033
42	20.5	4.2	0.0	4.2	.584	.179	.075	.029
45	20.6	4.5	0.0	4.5	.652	.201	.096	.010
48	20.5	4.9	0.0	4.9	.715	.221	.109	.003
51	20.5	5.2	0.0	5.2	.794	.239	.119	.002
54	20.6	4.9	0.0	4.9	.788	.246	.129	-.012
57	20.5	4.5	0.0	4.5	.799	.244	.128	-.012
60	20.5	4.2	0.0	4.2	.799	.238	.130	-.021
63	20.5	3.9	0.0	3.9	.793	.232	.127	-.021
66	20.5	3.6	0.0	3.6	.798	.218	.124	-.030
69	20.5	3.3	0.0	3.3	.792	.207	.120	-.034
72	20.5	3.0	0.0	3.0	.787	.195	.117	-.040
75	20.5	2.7	0.0	2.7	.775	.186	.113	-.039
78	20.5	2.4	0.0	2.4	.752	.171	.108	-.044
81	20.5	2.1	0.0	2.1	.735	.158	.104	-.050
84	20.5	1.8	0.0	1.8	.707	.143	.098	-.053
87	20.5	1.5	0.0	1.5	.689	.133	.094	-.055
90	20.5	1.2	0.0	1.2	.660	.116	.089	-.063
93	20.5	.9	0.0	.9	.626	.103	.081	-.059
96	20.6	.6	0.0	.6	.592	.088	.075	-.061
99	20.5	.3	0.0	.3	.523	.071	.069	-.067
102	20.5	0.0	0.0	0.0	.448	.047	.059	-.071

Definitions: CONF- confining pressure; DEV - deviator stress; POT - potentiometer; DIAM - diametral; MPa - megapascals; ms - millistrain.

TABLE IIb LOAD TEST #6.2

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT ms	GAUGE ms	GAUGE ms	GAUGE ms
0	20.5	10.0	10.0	0.0	0.000		0.000	
5	20.5	10.3	10.0	.3	.011		0.000	
10	20.5	10.6	10.0	.6	.016		.008	
15	20.5	10.9	10.0	.9	.046		.012	
20	20.5	11.2	10.0	1.2	.080		.013	
25	20.5	11.5	10.0	1.5	.102		.017	
30	20.5	11.8	10.0	1.8	.125		.022	
35	20.5	12.1	10.0	2.1	.152		.029	
40	20.5	12.4	10.0	2.4	.186		.030	
45	20.5	12.7	10.0	2.7	.220		.039	
50	20.5	13.0	10.0	3.0	.262		.049	
55	20.5	13.3	10.0	3.3	.315		.058	
60	20.6	13.6	10.0	3.6	.368		.066	
65	20.5	13.9	10.0	3.9	.421		.077	
70	20.5	14.2	10.0	4.2	.497		.094	
75	20.6	14.5	10.0	4.5	.599		.110	
80	20.5	14.8	10.0	4.9	.665		.126	
85	20.5	15.2	10.0	5.2	.737		.144	
90	20.5	15.5	10.0	5.5	.836		.160	
95	20.6	15.8	10.0	5.8	.946		.185	
100	20.6	16.1	10.0	6.1	1.042		.206	
105	20.6	16.4	10.0	6.4	1.144		.231	
110	20.6	16.1	10.0	6.1	1.148		.229	
115	20.6	15.8	10.0	5.8	1.148		.230	
120	20.6	15.5	10.0	5.5	1.144		.231	
125	20.6	15.2	10.0	5.2	1.151		.227	
130	20.6	14.8	10.0	4.9	1.151		.225	
135	20.6	14.5	10.0	4.5	1.144		.222	
140	20.6	14.2	10.0	4.2	1.152		.220	
145	20.6	13.9	10.0	3.9	1.148		.216	
150	20.6	13.6	10.0	3.6	1.150		.213	
155	20.6	13.3	10.0	3.3	1.147		.210	
160	20.6	13.0	10.0	3.0	1.147		.206	
165	20.6	12.7	10.0	2.7	1.139		.201	
170	20.6	12.4	10.0	2.4	1.143		.198	
175	20.6	12.1	10.0	2.1	1.135		.194	
180	20.6	11.8	10.0	1.8	1.113		.192	
185	20.6	11.5	10.0	1.5	1.120		.188	
190	20.7	11.2	10.0	1.2	1.113		.185	
195	20.7	10.9	10.0	.9	1.117		.180	
200	20.6	10.6	10.0	.6	1.102		.177	
205	20.7	10.3	10.0	.3	1.101		.175	
210	20.7	10.0	10.0	0.0	1.094		.171	

TABLE IIc LOAD TEST #6.3

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	VOL
					ms	ms	ms	ms
0	20.6	20.0	20.0	0.0	0.000		0.000	
5	20.6	20.3	20.0	.3	-.002		0.000	
10	20.6	20.6	20.0	.6	.100		.003	
15	20.6	20.9	20.0	.9	.135		.009	
20	20.6	21.2	20.0	1.2	.158		.014	
25	20.6	21.5	20.0	1.5	.196		.020	
30	20.6	21.8	20.0	1.8	.226		.025	
35	20.6	22.1	20.0	2.1	.257		.032	
40	20.7	22.4	20.0	2.4	.283		.039	
45	20.7	22.7	20.0	2.7	.328		.046	
50	20.6	23.0	20.0	3.0	.370		.057	
55	20.6	23.3	20.0	3.3	.404		.066	
60	20.6	23.6	20.0	3.6	.438		.071	
65	20.7	23.9	20.0	3.9	.484		.081	
70	20.7	24.2	20.0	4.2	.537		.092	
75	20.6	24.5	20.0	4.5	.594		.104	
80	20.7	24.8	20.0	4.9	.639		.116	
85	20.6	25.2	20.0	5.2	.708		.131	
90	20.7	25.5	20.0	5.5	.775		.143	
95	20.7	25.8	20.0	5.8	.859		.162	
100	20.7	26.1	20.0	6.1	.920		.180	
105	20.7	26.4	20.0	6.4	.989		.198	
110	20.7	26.1	20.0	6.1	.999		.196	
115	20.7	25.8	20.0	5.8	.999		.194	
120	20.7	25.5	20.0	5.5	.996		.192	
125	20.8	25.2	20.0	5.2	1.003		.192	
130	20.7	24.8	20.0	4.9	1.003		.187	
135	20.8	24.5	20.0	4.5	1.000		.185	
140	20.8	24.2	20.0	4.2	.999		.183	
145	20.8	23.9	20.0	3.9	.998		.180	
150	20.8	23.6	20.0	3.6	.995		.178	
155	20.8	23.3	20.0	3.3	.995		.173	
160	20.8	23.0	20.0	3.0	.991		.170	
165	20.8	22.7	20.0	2.7	.986		.167	
170	20.8	22.4	20.0	2.4	.986		.162	
175	20.8	22.1	20.0	2.1	.986		.160	
180	20.8	21.8	20.0	1.8	.975		.154	
185	20.8	21.5	20.0	1.5	.971		.151	
190	20.8	21.2	20.0	1.2	.967		.148	
195	20.9	20.9	20.0	.9	.956		.144	
200	20.9	20.6	20.0	.6	.959		.139	
205	20.8	20.3	20.0	.3	.951		.137	
210	20.9	20.0	20.0	0.0	.936		.133	

TABLE IIId LOAD TEST #6.4

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C		MPa	MPa	MPa	POT	GAUGE	GAUGE
			MPa	MPa	MPa	ms	ms	ms
0	20.9		30.0	30.0	0.0	0.000		0.000
5	20.9		30.3	30.0	.3	.003		.002
10	21.0		30.6	30.0	.6	.109		.008
15	20.9		30.9	30.0	.9	.131		.013
20	20.9		31.2	30.0	1.2	.157		.017
25	20.9		31.5	30.0	1.5	.179		.026
30	20.9		31.8	30.0	1.8	.205		.031
35	20.9		32.1	30.0	2.1	.217		.039
40	20.9		32.4	30.0	2.4	.239		.043
45	20.9		32.7	30.0	2.7	.273		.048
50	20.9		33.0	30.0	3.0	.299		.054
55	21.0		33.3	30.0	3.3	.344		.063
60	20.9		33.6	30.0	3.6	.367		.072
65	20.9		33.9	30.0	3.9	.401		.080
70	20.9		34.2	30.0	4.2	.431		.087
75	20.9		34.5	30.0	4.6	.465		.094
80	20.9		34.8	30.0	4.9	.507		.105
85	21.0		35.1	30.0	5.2	.533		.114
90	20.9		35.5	30.0	5.5	.582		.122
95	21.0		35.8	30.0	5.8	.628		.135
100	21.0		36.1	30.0	6.1	.681		.148
105	21.0		36.4	30.0	6.4	.722		.162
110	20.9		36.1	30.0	6.1	.722		.160
115	21.0		35.8	30.0	5.8	.722		.160
120	21.0		35.5	30.0	5.5	.722		.159
125	21.0		35.1	30.0	5.2	.725		.158
130	21.0		34.8	30.0	4.9	.718		.156
135	21.0		34.5	30.0	4.6	.718		.155
140	21.0		34.2	30.0	4.2	.721		.150
145	21.0		33.9	30.0	3.9	.725		.147
150	21.1		33.6	30.0	3.6	.721		.144
155	21.0		33.3	30.0	3.3	.717		.141
160	21.0		33.0	30.0	3.0	.725		.139
165	21.0		32.7	30.0	2.7	.724		.137
170	21.0		32.4	30.0	2.4	.713		.133
175	21.1		32.1	30.0	2.1	.720		.131
180	21.1		31.8	30.0	1.8	.708		.127
185	21.0		31.5	30.0	1.5	.705		.124
190	21.1		31.2	30.0	1.2	.705		.120
195	21.1		30.9	30.0	.9	.704		.118
200	21.1		30.6	30.0	.6	.689		.114
205	21.1		30.3	30.0	.3	.682		.109
210	21.1		30.0	30.0	0.0	.678		.105

TABLE IIe LOAD TEST #6.5

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT ms	GAUGE ms	GAUGE ms	GAUGE ms
0	20.8	40.0	40.0	0.0	0.000		0.000	
5	20.8	40.3	40.0	.3	.016		.005	
10	20.8	40.6	40.0	.6	.031		.009	
15	20.9	40.9	40.0	.9	.042		.011	
20	20.8	41.2	40.0	1.2	.042		.014	
25	20.8	41.5	40.0	1.5	.050		.018	
30	20.8	41.8	40.0	1.8	.068		.025	
35	20.8	42.1	40.0	2.1	.064		.030	
40	20.9	42.4	40.0	2.4	.087		.033	
45	20.9	42.7	40.0	2.7	.098		.038	
50	20.8	43.0	40.0	3.0	.097		.043	
55	20.9	43.3	40.0	3.3	.170		.049	
60	20.9	43.6	40.0	3.6	.173		.055	
65	20.9	43.9	40.0	3.9	.196		.060	
70	20.8	44.2	40.0	4.2	.214		.066	
75	20.9	44.5	40.0	4.5	.245		.071	
80	20.9	44.8	40.0	4.9	.256		.080	
85	20.9	45.1	40.0	5.2	.275		.088	
90	20.9	45.4	40.0	5.5	.362		.094	
95	20.9	45.8	40.0	5.8	.389		.104	
100	20.9	46.1	40.0	6.1	.415		.111	
105	20.9	46.4	40.0	6.4	.446		.121	
110	20.9	46.1	40.0	6.1	.453		.121	
115	20.9	45.8	40.0	5.8	.449		.119	
120	20.9	45.4	40.0	5.5	.448		.118	
125	20.9	45.1	40.0	5.2	.449		.115	
130	20.9	44.8	40.0	4.9	.444		.113	
135	20.9	44.5	40.0	4.5	.441		.110	
140	20.9	44.2	40.0	4.2	.448		.101	
145	21.0	43.9	40.0	3.9	.437		.103	
150	21.0	43.6	40.0	3.6	.447		.101	
155	21.0	43.3	40.0	3.3	.448		.098	
160	21.0	43.0	40.0	3.0	.451		.095	
165	20.9	42.7	40.0	2.7	.440		.092	
170	21.0	42.4	40.0	2.4	.447		.088	
175	21.0	42.1	40.0	2.1	.443		.085	
180	21.0	41.8	40.0	1.8	.443		.083	
185	21.0	41.5	40.0	1.5	.439		.080	
190	21.0	41.2	40.0	1.2	.432		.078	
195	21.0	40.9	40.0	.9	.424		.075	
200	21.0	40.6	40.0	.6	.424		.071	
205	21.0	40.3	40.0	.3	.420		.068	
210	21.0	40.0	40.0	0.0	.416		.066	

TABLE II f LOAD TEST #6.6

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C		MPa	MPa	MPa	POT	GAUGE	GAUGE
						ms	ms	ms
0	20.8		40.0	40.0	0.0	0.000		0.000
5	20.8		40.6	40.0	.6	-.005		.003
10	20.7		41.2	40.0	1.2	-.002		.007
15	20.8		41.8	40.0	1.8	.002		.013
20	20.8		42.4	40.0	2.4	.003		.019
25	20.8		43.0	40.0	3.0	.011		.026
30	20.7		43.6	40.0	3.6	.019		.034
35	20.8		44.2	40.0	4.2	.019		.039
40	20.8		44.8	40.0	4.9	.037		.047
45	20.8		45.4	40.0	5.5	.072		.056
50	20.8		46.1	40.0	6.1	.136		.066
55	20.8		46.7	40.0	6.7	.197		.081
60	20.8		47.3	40.0	7.3	.239		.098
65	20.8		47.9	40.0	7.9	.311		.120
70	20.8		48.5	40.0	8.5	.372		.141
75	20.8		49.1	40.0	9.1	.455		.166
80	20.8		49.7	40.0	9.7	.535		.194
85	20.9		50.3	40.0	10.3	.633		.228
90	20.8		50.9	40.0	10.9	.728		.260
95	20.8		51.5	40.0	11.5	.816		.299
100	20.8		52.1	40.0	12.1	.926		.338
105	20.8		52.7	40.0	12.7	1.048		.385
110	20.9		53.3	40.0	13.3	1.181		.436
115	20.8		53.9	40.0	14.0	1.310		.486
120	20.9		54.5	40.0	14.6	1.458		.541
125	20.9		55.2	40.0	15.2	1.596		.603
130	20.8		55.8	40.0	15.8	1.762		.669
135	20.9		56.4	40.0	16.4	1.953		.748
140	20.9		57.0	40.0	17.0	2.143		.825
145	20.9		57.6	40.0	17.6	2.345		.918
150	20.9		58.2	40.0	18.2	2.565		1.012
155	20.9		58.8	40.0	18.8	2.797		1.108
160	20.9		59.4	40.0	19.4	3.048		1.225
165	20.9		60.0	40.0	20.0	3.299		1.331
170	20.9		60.6	40.0	20.6	3.592		1.460
175	20.9		61.2	40.0	21.2	3.874		1.606
180	20.9		61.8	40.0	21.8	4.201		1.770
185	20.9		62.4	40.0	22.4	4.559		1.960
190	20.9		63.0	40.0	23.0	4.947		2.159
195	21.0		63.6	40.0	23.7	5.343		2.422
200	20.9		64.2	40.0	24.3	5.762		2.697
205	20.9		64.9	40.0	24.9	6.257		3.034
210	21.0		65.5	40.0	25.5	6.782		3.418

TABLE II: LOAD TEST #6.6

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL POT	AXIAL GAUGE	DIAM GAUGE	VOL GAUGE
mins	deg C	MPa	MPa	MPa	ms	ms	ms	ms
215	21.0	66.1	40.0	26.1	7.346		3.903	
220	21.0	66.7	40.0	26.7	7.913		3.482	
225	21.0	67.3	40.0	27.3	8.629		3.760	
230	21.0	67.9	40.0	27.9	9.432		4.085	
235	21.0	68.5	40.0	28.5	10.338		4.443	
240	21.0	69.1	40.0	29.1	11.287		4.812	
245	21.0	69.7	40.0	29.7	12.367		5.237	
250	21.0	70.3	40.0	30.3	13.628		5.723	
255	21.0	70.9	40.0	30.9	15.147		6.341	
260	21.0	71.5	40.0	31.5	16.378		6.895	
265	21.0	72.1	40.0	32.1	18.448		7.720	
270	21.0	72.7	40.0	32.8	20.921		8.733	
275	21.1	73.3	40.0	33.4	23.237		9.674	

TABLE IIg LOAD TEST #7.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C		MPa	MPa	MPa	POT	GAUGE	GAUGE
			MPa	MPa	MPa	ms	ms	ms
0	21.7		.5	-.1	.7	0.000	0.000	0.000
5	21.7		.8	-.1	.9	.011	.001	-.013
10	21.6		1.1	-.1	1.3	.049	.020	.008
15	21.6		1.4	-.1	1.6	.079	.041	.031
20	21.6		1.8	-.1	1.9	.109	.042	.032
25	21.7		2.1	-.1	2.2	.124	.082	.062
30	21.7		2.4	-.1	2.5	.158	.109	.089
35	21.6		2.6	-.1	2.8	.191	.137	.117
40	21.7		2.9	-.1	3.1	.230	.162	.142
45	21.7		3.2	-.1	3.4	.271	.194	.174
50	21.7		3.6	-.1	3.7	.312	.232	.212
55	21.7		3.9	-.1	4.0	.354	.275	.249
60	21.7		4.2	-.1	4.4	.384	.316	.286
65	21.7		4.5	-.1	4.6	.433	.363	.333
70	21.7		4.8	-.1	4.9	.554	.407	.375
75	21.7		5.1	-.1	5.2	.675	.468	.432
80	21.7		5.4	-.1	5.5	.792	.526	.480
85	21.7		5.8	-.1	5.9	.921	.597	.511
90	21.7		5.4	-.1	5.5	.924	.594	.506
95	21.7		5.1	-.1	5.3	.924	.591	.523
100	21.8		4.8	-.1	5.0	.921	.585	.517
105	21.8		4.6	-.1	4.7	.928	.578	.518
110	21.8		4.3	-.1	4.4	.921	.562	.508
115	21.8		4.0	-.1	4.1	.921	.547	.493
120	21.8		3.7	-.1	3.8	.921	.527	.479
125	21.8		3.4	-.1	3.5	.920	.506	.468
130	21.8		3.1	-.1	3.2	.917	.486	.450
135	21.8		2.8	-.1	2.9	.913	.464	.436
140	21.8		2.5	-.1	2.6	.909	.442	.418
145	21.8		2.2	-.1	2.3	.901	.419	.405
150	21.8		1.9	-.1	2.0	.879	.395	.383
155	21.8		1.6	-.1	1.7	.875	.369	.359
160	21.8		1.3	-.1	1.4	.860	.342	.334
165	21.9		1.0	-.1	1.1	.837	.317	.317
170	21.8		.4	-.1	.6	.784	.262	.262

TABLE IIh LOAD TEST #7.2

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	VOL
					ms	ms	ms	GAUGE
								ms
0	21.7	10.2	9.8	.4	0.000	0.000	0.000	0.000
5	21.7	10.6	9.8	.8	.008	.025	.009	.007
10	21.7	10.8	9.8	1.0	.045	.046	.012	.022
15	21.7	11.1	9.9	1.2	.087	.075	.014	.047
20	21.7	11.4	9.9	1.5	.136	.117	.019	.079
25	21.8	11.7	9.8	1.9	.193	.164	.030	.104
30	21.7	12.0	9.8	2.2	.261	.214	.038	.138
35	21.7	12.4	9.9	2.5	.348	.277	.047	.183
40	21.8	12.6	9.9	2.8	.431	.345	.057	.231
45	21.7	12.9	9.9	3.1	.525	.415	.064	.287
50	21.8	13.1	9.9	3.3	.635	.493	.077	.339
55	21.8	13.6	9.9	3.7	.752	.586	.092	.402
60	21.8	13.9	9.9	4.0	.873	.687	.109	.469
65	21.8	14.1	9.9	4.2	.994	.782	.125	.532
70	21.8	14.5	9.9	4.6	1.119	.891	.145	.601
75	21.8	14.7	9.9	4.8	1.259	1.019	.165	.689
80	21.8	15.0	9.9	5.2	1.418	1.143	.185	.773
85	21.8	15.4	9.9	5.5	1.577	1.293	.212	.869
90	21.8	15.7	9.9	5.8	1.747	1.449	.243	.963
95	21.8	15.9	9.9	6.0	1.932	1.621	.267	1.087
100	21.8	16.2	9.9	6.3	2.110	1.790	.300	1.190
105	21.8	16.5	9.9	6.6	2.315	1.965	.334	1.297
110	21.8	16.2	9.9	6.4	2.367	2.009	.340	1.329
115	21.8	15.9	9.9	6.0	2.386	2.025	.342	1.341
120	21.8	15.6	9.9	5.7	2.391	2.029	.342	1.345
125	21.8	15.3	9.9	5.4	2.395	2.033	.342	1.349
130	21.8	15.1	9.9	5.2	2.395	2.033	.340	1.353
135	21.8	14.7	9.9	4.9	2.402	2.031	.342	1.347
140	21.8	14.5	9.9	4.6	2.406	2.024	.342	1.340
145	21.8	14.2	9.9	4.3	2.406	2.019	.334	1.351
150	21.8	13.9	9.9	4.0	2.402	2.002	.331	1.340
155	21.9	13.6	9.9	3.7	2.398	1.994	.327	1.340
160	21.9	13.3	9.9	3.5	2.402	1.981	.324	1.333
165	21.8	13.0	9.9	3.2	2.398	1.968	.324	1.320
170	21.9	12.6	9.9	2.8	2.398	1.946	.320	1.306
175	21.9	12.4	9.9	2.5	2.405	1.933	.316	1.301
180	21.9	12.1	9.9	2.2	2.398	1.913	.313	1.287
185	21.9	11.8	9.9	1.9	2.386	1.899	.307	1.285
190	21.9	11.5	9.9	1.6	2.394	1.875	.302	1.271
195	21.9	11.1	9.9	1.2	2.386	1.860	.300	1.260
200	21.9	10.8	9.9	.9	2.379	1.839	.296	1.247
205	21.9	10.5	9.9	.7	2.367	1.824	.290	1.244
210	21.9	10.2	9.9	.4	2.360	1.798	.286	1.226

TABLE III: LOAD TEST #7.3

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	VOL
					ms	ms	ms	ms
0	21.2	18.4	19.1	-7	0.000	0.000	0.000	0.000
5	21.3	18.6	19.1	-5	.007	.006	-.004	.014
10	21.2	18.7	19.1	-3	.010	.008	-.004	.016
15	21.2	19.2	19.1	.1	.062	-.002	.014	-.030
20	21.2	19.5	19.1	.4	.127	-.001	.025	-.051
25	21.2	19.8	19.1	.7	.168	-.002	.036	-.074
30	21.2	20.1	19.1	1.0	.225	-.002	.051	-.104
35	21.2	20.3	19.1	1.2	.304	-.002	.075	-.152
40	21.2	20.7	19.1	1.6	.421	-.006	.111	-.228
45	21.2	21.0	19.1	1.9	.523	-.002	.150	-.302
50	21.2	21.4	19.0	2.3	.628	.008	.191	-.375
55	21.3	21.6	19.1	2.5	.742	.031	.240	-.449
60	21.2	21.9	19.1	2.8	.829	.063	.266	-.470
65	21.2	22.1	19.1	3.0	.953	.103	.300	-.497
70	21.2	22.6	19.0	3.6	1.090	.134	.343	-.553
75	21.3	22.9	19.1	3.8	1.263	.229	.386	-.544
80	21.2	23.2	19.1	4.1	1.350	.304	.413	-.522
85	21.3	23.6	19.1	4.5	1.430	.380	.439	-.498
90	21.2	23.2	19.1	4.1	1.456	.400	.445	-.491
95	21.3	22.8	19.1	3.7	1.459	.407	.446	-.486
100	21.2	22.4	19.1	3.4	1.452	.406	.446	-.487
105	21.3	22.2	19.1	3.1	1.459	.409	.445	-.482
110	21.3	21.9	19.1	2.8	1.459	.412	.445	-.479
115	21.2	21.6	19.1	2.6	1.462	.412	.447	-.483
120	21.3	21.4	19.1	2.4	1.455	.412	.447	-.483
125	21.3	21.1	19.1	2.0	1.458	.407	.442	-.477
130	21.3	20.8	19.1	1.8	1.447	.403	.438	-.474
135	21.3	20.5	19.1	1.4	1.450	.400	.438	-.477
140	21.3	20.2	19.1	1.1	1.454	.395	.435	-.476
145	21.3	19.9	19.1	.9	1.461	.395	.431	-.467
150	21.3	19.6	19.1	.5	1.454	.395	.426	-.457
155	21.4	19.3	19.1	.3	1.457	.395	.421	-.447
160	21.3	19.0	19.1	-.1	1.439	.399	.416	-.433
165	21.4	18.7	19.1	-.4	1.431	.409	.414	-.420
170	21.3	18.4	19.0	-.6	1.426	.418	.406	-.395

TABLE II; LOAD TEST #7.4

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	GAUGE
					ms	ms	ms	ms
0	21.2	24.9	25.0	-.1	0.000	0.000	0.000	0.000
5	21.2	25.1	25.0	.2	.037	-.003	.002	-.007
10	21.2	25.5	24.9	.5	.048	-.010	.014	-.038
15	21.2	25.8	25.0	.8	.078	-.012	.024	-.060
20	21.2	26.0	25.0	1.1	.119	-.010	.032	-.074
25	21.2	26.4	24.9	1.4	.172	-.002	.049	-.100
30	21.2	26.7	25.0	1.7	.266	-.022	.072	-.166
35	21.2	27.0	25.0	2.1	.338	-.035	.104	-.243
40	21.2	27.3	25.0	2.3	.413	-.037	.126	-.289
45	21.2	27.6	25.0	2.7	.481	-.020	.162	-.344
50	21.2	27.9	25.0	3.0	.578	-.013	.199	-.411
55	21.2	28.3	25.0	3.3	.665	.020	.232	-.445
60	21.2	28.6	25.0	3.6	.737	.045	.252	-.459
65	21.2	28.9	25.0	4.0	.827	.085	.284	-.484
70	21.2	29.2	25.0	4.2	.947	.129	.316	-.503
75	21.2	29.5	25.0	4.5	1.028	.173	.342	-.511
80	21.2	29.9	25.0	4.9	1.122	.233	.370	-.507
85	21.3	30.3	25.0	5.3	1.205	.301	.401	-.502
90	21.2	29.8	25.0	4.8	1.223	.310	.403	-.497
95	21.2	29.5	25.0	4.5	1.238	.319	.406	-.494
100	21.2	29.2	25.0	4.2	1.238	.322	.408	-.494
105	21.2	28.9	25.0	3.9	1.242	.324	.410	-.496
110	21.2	28.6	25.0	3.6	1.235	.326	.409	-.492
115	21.3	28.3	24.9	3.4	1.242	.326	.412	-.499
120	21.2	28.0	24.9	3.1	1.238	.325	.410	-.495
125	21.2	27.7	24.9	2.8	1.238	.323	.409	-.496
130	21.2	27.4	25.0	2.5	1.234	.320	.405	-.490
135	21.3	27.2	24.9	2.2	1.234	.318	.404	-.491
140	21.3	26.9	24.9	1.9	1.242	.316	.399	-.483
145	21.3	26.6	24.9	1.6	1.245	.316	.395	-.474
150	21.3	26.2	24.9	1.3	1.237	.314	.389	-.465
155	21.3	25.9	24.9	1.0	1.233	.312	.387	-.462
160	21.3	25.6	24.9	.6	1.229	.313	.382	-.451
165	21.3	25.2	24.9	.3	1.207	.317	.377	-.438
170	21.3	24.9	24.9	-.0	1.191	.320	.372	-.425

TABLE IIk LOAD TEST #7.5

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	GAUGE
					ms	ms	ms	ms
	21.0	24.9	24.9	-.0	0.000	0.000	0.000	0.000
5	21.0	26.5	25.0	1.5	.036	-.014	.023	-.060
10	20.9	28.0	25.0	3.0	.153	.014	.056	-.099
15	20.9	29.6	24.9	4.6	.285	.125	.098	-.072
20	21.0	31.1	25.0	6.2	.474	.340	.166	.008

TABLE III CREEP TEST #7.5

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	GAUGE
					ms	ms	ms	ms
0	21.0	31.2	24.9	6.2	.000	0.000	0.000	0.000
5	21.0	31.1	25.0	6.1	.026	.029	.008	.013
10	20.9	31.0	25.0	6.1	.041	.053	.016	.021
15	21.0	31.1	25.0	6.1	.075	.081	.023	.035
20	21.0	31.1	25.0	6.1	.094	.104	.030	.044
25	21.0	31.1	25.0	6.1	.113	.125	.035	.055
30	20.9	31.2	25.0	6.2	.131	.156	.043	.070
35	21.0	31.0	25.0	6.1	.146	.171	.045	.081
40	21.0	31.1	25.0	6.2	.172	.197	.052	.093
45	21.0	31.1	25.0	6.1	.187	.211	.059	.093
50	21.0	31.1	25.0	6.2	.210	.234	.066	.102
55	20.9	31.1	25.0	6.1	.236	.258	.070	.118
60	21.0	31.1	25.0	6.1	.243	.272	.076	.120
65	21.0	31.0	25.0	6.1	.266	.290	.081	.128
70	21.0	31.1	25.0	6.1	.280	.307	.083	.141
80	21.0	31.1	25.0	6.1	.322	.343	.091	.161
90	21.0	31.1	24.9	6.1	.348	.379	.102	.175
100	21.0	31.1	25.0	6.1	.375	.410	.111	.188
110	21.0	31.1	25.0	6.1	.408	.440	.121	.198
120	21.0	31.0	25.0	6.1	.445	.472	.128	.216
135	21.0	31.1	25.0	6.1	.472	.517	.142	.233
150	21.0	31.1	25.0	6.1	.524	.564	.155	.254
165	21.0	31.1	25.0	6.1	.566	.601	.169	.263
180	21.0	31.1	25.0	6.1	.615	.642	.180	.282
195	21.0	31.1	24.9	6.2	.655	.686	.190	.306
210	21.1	31.1	25.0	6.1	.682	.720	.198	.324
225	21.1	31.1	25.0	6.1	.724	.757	.210	.337
240	21.1	31.1	24.9	6.2	.761	.794	.220	.354
255	21.1	31.1	24.9	6.1	.803	.827	.230	.367
270	21.1	31.1	24.9	6.1	.828	.863	.240	.383
330	21.2	30.1	25.0	5.1	.884			
390	21.1	29.5	25.0	4.4	.905			
450	21.1	29.0	25.0	4.0	.923			
510	21.1	28.7	25.0	3.6	.940			
570	21.0	28.4	25.0	3.4	.931			
630	21.1	28.2	25.0	3.1	.958			
690	21.1	27.9	25.0	2.9	.961			
750	21.1	27.7	25.0	2.8	.953			
810	21.0	27.6	25.0	2.6	.980			
842	21.0	27.5	25.0	2.6	.968	.971	.262	.447
845	21.0	31.0	25.0	6.1	1.180	1.171	.316	.539
905	21.0	30.0	25.0	5.1	1.205			
954	21.0	29.6	25.0	4.6	1.228	1.211	.330	.551

TABLE III CREEP TEST #7.5

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT ms	GAUGE ms	GAUGE ms	GAUGE ms
967	21.0	31.0	25.0	6.1	1.367	1.314	.361	.592
1020	21.0	30.2	25.0	5.2	1.348	1.334	.366	.602
1025	21.0	31.2	25.0	6.2	1.416	1.390	.381	.628
1087	21.0	30.2	25.0	5.2	1.412	1.413	.391	.631
1091	21.0	31.2	24.9	6.2	1.503	1.477	.408	.661
1151	21.0	30.3	25.0	5.3	1.504			
1211	21.0	29.8	25.0	4.8	1.546			
1215	21.1	29.8	25.0	4.8	1.546	1.515	.424	.667
1218	21.1	31.2	24.9	6.2	1.637	1.593	.447	.699
1278	21.1	30.3	25.0	5.3	1.621	1.609	.450	.709
1282	21.0	31.2	24.9	6.3	1.697	1.655	.463	.729
1342	21.1	30.4	25.0	5.4	1.691	1.674	.474	.726
1346	21.1	31.1	24.9	6.1	1.747	1.707	.482	.743
1400	21.2	30.4	25.0	5.4	1.742	1.726	.484	.758
1402	21.1	31.2	24.9	6.3	1.810	1.777	.499	.779
1432	21.2	31.1	24.9	6.2	1.817	1.803	.507	.789
1462	21.2	31.1	24.9	6.2	1.851	1.841	.519	.803
1492	21.2	31.1	24.9	6.2	1.884	1.876	.536	.804
1522	21.2	31.1	24.9	6.2	1.922	1.907	.544	.819
1552	21.3	31.2	24.9	6.2	1.971	1.946	.562	.822
1582	21.3	31.1	24.9	6.2	2.000	1.973	.571	.831
1612	21.3	31.2	24.9	6.3	2.035	2.008	.578	.852
1642	21.3	30.8	25.0	5.9	2.030	2.017	.583	.851
1672	21.3	30.8	25.0	5.8	2.057	2.042	.600	.842
1702	21.4	30.8	25.0	5.8	2.087	2.062	.609	.844
1732	21.4	30.8	25.0	5.8	2.121	2.085	.612	.861
1762	21.4	30.8	25.0	5.9	2.154			
1792	21.4	30.6	25.0	5.6	2.169			
1822	21.5	30.3	25.0	5.3	2.178			
1852	21.5	30.2	25.0	5.1	2.183			
1882	21.4	30.0	25.1	4.9	2.201			
1912	21.5	29.8	25.1	4.8	2.202			
1942	21.4	29.7	25.1	4.6	2.214			
1972	21.4	29.6	25.1	4.5	2.211			
2002	21.4	29.5	25.1	4.4	2.216			
2032	21.4	29.3	25.1	4.3	2.220			
2062	21.4	29.2	25.1	4.2	2.217			
2092	21.4	29.1	25.1	4.1	2.225			
2122	21.3	29.1	25.1	4.0	2.226			
2152	21.3	29.0	25.1	3.9	2.227			
2182	21.3	28.9	25.1	3.8	2.235			
2212	21.2	28.8	25.0	3.8	2.239			
2242	21.3	28.7	25.0	3.7	2.242			
2272	21.3	28.7	25.0	3.6	2.240			

TABLE III CREEP TEST #7.5

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	GAUGE
					ms	ms	ms	ms
2284	21.3	28.6	25.0	3.6	2.248	2.177	.640	.897
2288	21.3	31.3	24.9	6.3	2.414	2.316	.675	.966
2318	21.3	30.7	24.9	5.8	2.426			
2348	21.3	30.5	24.9	5.5	2.423	2.326	.680	.966
2351	21.3	31.1	25.0	6.1	2.466	2.357	.688	.981
2381	21.2	30.7	25.0	5.8	2.469			
2371	21.2	30.4	25.0	5.5	2.470	2.371	.695	.981
2413	21.2	31.0	25.0	6.0	2.508	2.396	.702	.992
2443	21.2	30.6	25.0	5.7	2.501			
2473	21.2	30.4	25.0	5.4	2.494	2.405	.706	.993
2476	21.2	31.0	25.0	6.1	2.540	2.436	.713	1.010
2506	21.2	30.7	25.0	5.7	2.538			
2536	21.2	30.5	25.0	5.5	2.529	2.445	.717	1.011
2539	21.2	31.1	24.9	6.2	2.575	2.477	.728	1.021
2569	21.2	30.8	25.0	5.8	2.573			
2599	21.2	30.5	25.0	5.6	2.572	2.491	.731	1.029
2603	21.2	31.1	25.0	6.1	2.620	2.517	.737	1.043
2633	21.2	30.7	25.0	5.8	2.605			
2663	21.2	30.5	25.0	5.6	2.612	2.527	.741	1.045
2666	21.2	31.2	24.9	6.2	2.662	2.556	.754	1.048
2696	21.2	30.8	25.0	5.9	2.661			
2726	21.2	30.6	25.0	5.7	2.664	2.571	.759	1.053
2728	21.3	31.1	25.0	6.1	2.687	2.595	.763	1.069
2758	21.3	30.8	25.0	5.8	2.694			
2788	21.3	30.6	25.0	5.6	2.690	2.605	.768	1.069
2791	21.3	31.1	24.9	6.1	2.717	2.630	.775	1.080
2821	21.3	30.8	24.9	5.8	2.726			
2851	21.3	31.0	25.0	6.1	2.756	2.667	.789	1.089
2881	21.3	31.1	24.9	6.2	2.778	2.695	.800	1.095
2911	21.4	31.2	24.9	6.3	2.802	2.718	.809	1.100
2941	21.4	31.1	24.9	6.2	2.812	2.732	.813	1.106
2971	21.4	31.1	24.9	6.2	2.831	2.750	.821	1.108
3001	21.4	31.1	24.9	6.2	2.861	2.766	.827	1.112
3061	21.4	30.8	25.0	5.8	2.890			
3121	21.5	30.5	25.0	5.5	2.901			
3181	21.4	30.2	25.0	5.2	2.921			
3241	21.4	30.0	25.0	4.9	2.928			
3301	21.4	29.7	25.0	4.7	2.940			
3361	21.4	29.6	25.0	4.6	2.941			
3421	21.3	29.4	25.0	4.4	2.942			
3481	21.3	29.2	25.0	4.3	2.946			
3541	21.2	29.2	25.0	4.2	2.941			
3601	21.3	29.0	24.9	4.1	2.956			
3661	21.2	28.9	24.9	3.9	2.963			

TABLE III CREEP TEST #7.5

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C		MPa	MPa	MPa	POT	GAUGE	GAUGE
						ms	ms	ms
3718	21.2		28.8	24.9	3.9	2.948	2.843	.855
3721	21.2		31.0	25.0	6.1	3.081	2.953	.882
3781	21.2		30.5	25.0	5.5	3.090		
3821	21.2		30.2	24.9	5.3	3.095	2.961	.887
3823	21.2		31.0	25.0	6.1	3.141	2.996	.894
3883	21.1		30.6	24.9	5.6	3.121	3.001	.897
3885	21.1		31.1	25.0	6.2	3.159	3.026	.905
3945	21.1		30.6	25.0	5.7	3.173		
4005	21.1		30.3	24.9	5.4	3.170	3.042	.911
4007	21.1		31.1	25.0	6.1	3.238	3.077	.923
4067	21.1		30.6	25.0	5.7	3.231	3.083	.925
4070	21.1		31.1	25.0	6.1	3.249	3.104	.930
4121	21.0		30.7	25.0	5.8	3.252	3.110	.932
4124	21.1		31.1	25.0	6.1	3.263	3.130	.937
4184	21.1		30.7	25.0	5.7	3.289		
4244	21.1		30.4	25.0	5.5	3.287	3.145	.944
4247	21.1		31.0	25.0	6.1	3.343	3.172	.953
4286	21.1		30.7	25.0	5.8	3.336	3.177	.955
4289	21.1		31.1	24.9	6.2	3.359	3.196	.962
4349	21.1		31.1	24.9	6.2	3.368	3.226	.970
4409	21.1		31.2	24.9	6.2	3.384	3.257	.981
4442	21.1		31.2	24.9	6.2	3.402	3.271	.986
4502	21.2		30.8	25.0	5.9	3.413	3.281	.990
4506	21.2		31.1	25.0	6.1	3.428	3.292	.996
4566	21.2		30.7	25.0	5.8	3.444		
4626	21.2		30.5	25.0	5.5	3.454		
4686	21.2		30.3	25.0	5.3	3.468		
4746	21.2		30.1	25.0	5.1	3.462		
4806	21.2		29.9	25.0	4.9	3.474		
4866	21.1		29.8	25.0	4.8	3.475		
4926	21.1		29.7	25.0	4.7	3.484		
4986	21.1		29.5	25.0	4.6	3.468		
5046	21.1		29.4	25.0	4.4	3.493		
5106	21.1		29.3	25.0	4.3	3.510		
5166	21.1		29.2	24.9	4.3	3.502		
5219	21.0		29.1	24.9	4.2	3.517	3.337	1.012
5224	21.0		31.1	24.9	6.2	3.650	3.436	1.040
5284	21.0		30.7	24.9	5.8	3.647		
5344	21.0		30.5	24.9	5.5	3.651		
5404	21.0		30.2	24.9	5.3	3.657		
5464	20.9		30.1	24.9	5.2	3.639		
5524	21.0		29.9	24.9	5.0	3.649		
5564	21.0		29.8	24.9	4.9	3.657	3.464	1.053
5567	21.0		31.1	25.0	6.1	3.718	3.518	1.063

TABLE III CREEP TEST #7.5

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	GAUGE
					ms	ms	ms	ms
5627	21.0	31.0	24.9	6.1	3.727	3.547	1.078	1.391
5687	21.0	31.1	24.9	6.1	3.746	3.569	1.085	1.399
5747	21.1	31.2	24.9	6.2	3.771	3.599	1.093	1.413
5807	21.1	31.1	24.9	6.2	3.792	3.619	1.098	1.423
5867	21.1	30.9	25.0	5.9	3.812			
5927	21.1	30.7	25.0	5.7	3.823			
5987	21.1	30.5	25.0	5.4	3.818			
6047	21.1	30.3	25.0	5.3	3.827			
6107	21.1	30.2	25.0	5.1	3.815			
6167	21.1	30.0	25.0	5.0	3.838			
6227	21.1	29.9	25.0	4.9	3.847			
6287	21.1	29.8	25.0	4.8	3.834			
6347	21.1	29.7	25.0	4.7	3.842			
6407	21.0	29.6	25.0	4.6	3.850			
6467	21.1	29.5	25.0	4.5	3.876			
6527	21.0	29.4	25.0	4.4	3.875			
6587	21.0	29.3	25.0	4.3	3.873			
6647	21.0	29.2	25.0	4.2	3.872			
6707	21.0	29.2	24.9	4.2	3.864			
6767	21.0	29.1	24.9	4.1	3.871			
6827	21.0	29.0	24.9	4.1	3.857			
6887	21.0	28.9	24.9	4.0	3.871			
6947	21.0	28.9	24.9	4.0	3.853			
6985	21.0	28.8	24.9	3.9	3.866	3.674	1.129	1.416
6988	21.0	31.1	24.9	6.2	3.991	3.782	1.153	1.476
7048	21.0	30.7	25.0	5.7	4.008			
7108	21.0	30.5	25.0	5.6	3.994			
7168	21.0	30.3	25.0	5.4	4.005			
7228	21.0	30.2	24.9	5.2	3.997			
7288	20.9	30.0	24.9	5.1	4.013			
7348	21.0	29.9	24.9	5.0	4.009			
7408	20.9	29.8	24.9	4.8	4.014			
7424	20.9	29.8	24.9	4.8	4.016	3.803	1.162	1.479
7427	20.9	31.1	24.9	6.2	4.086	3.863	1.179	1.505
7487	20.9	30.8	24.9	5.8	4.080			
7547	20.9	30.5	24.9	5.6	4.089			
7607	20.9	30.4	24.9	5.4	4.087			
7667	20.9	30.2	24.9	5.3	4.094			
7727	20.9	30.1	24.9	5.2	4.098			
7787	20.9	30.0	24.9	5.0	4.100			
7847	20.9	29.9	24.9	4.9	4.091			
7907	20.9	29.8	24.9	4.8	4.105			
7967	20.9	29.7	24.9	4.8	4.099			
8027	20.9	29.6	24.9	4.7	4.094			

TABLE III CREEP TEST #7.5

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT ms	GAUGE ms	GAUGE ms	GAUGE ms
8047	20.9	29.6	24.9	4.7	4.099	3.898	1.198	1.502
8049	20.9	31.1	24.9	6.2	4.187	3.961	1.216	1.529
8109	20.9	30.8	25.0	5.8	4.207			
8160	20.8	30.6	25.0	5.7	4.195	3.971	1.225	1.521
8164	20.9	31.1	24.9	6.2	4.231	3.994	1.232	1.530
8224	20.9	30.8	25.0	5.8	4.236			
8284	20.9	30.7	25.0	5.7	4.217			
8344	21.0	30.6	25.0	5.6	4.207			
8404	21.1	30.5	25.0	5.4	4.224			
8464	21.1	30.3	25.1	5.3	4.225			
8524	21.1	30.2	25.1	5.1	4.231			
8584	21.1	30.2	25.1	5.0	4.241			
8591	21.1	30.1	25.1	5.0	4.241	4.016	1.235	1.546
8594	21.1	31.1	24.9	6.1	4.321	4.063	1.253	1.557
8654	21.1	31.1	24.9	6.1	4.316	4.086	1.258	1.570
8714	21.1	31.1	24.9	6.2	4.336	4.103	1.266	1.571
8774	21.1	31.1	24.9	6.2	4.362			
8834	21.1	30.9	25.0	5.9	4.369			
8894	21.1	30.7	25.0	5.7	4.376			
8954	21.1	30.6	25.0	5.6	4.382			
9014	21.1	30.5	25.0	5.5	4.373			
9074	21.1	30.4	25.0	5.4	4.372			
9134	21.2	30.3	25.0	5.3	4.357			
9194	21.3	30.2	25.0	5.2	4.360			
9254	21.3	30.2	25.1	5.1	4.371			
9314	21.4	30.1	25.1	5.0	4.388			
9374	21.4	30.0	25.1	4.9	4.384			
9434	21.4	30.0	25.2	4.8	4.380			
9484	21.5	29.9	25.2	4.7	4.398	4.151	1.292	1.567
9487	21.5	31.2	24.9	6.3	4.481	4.212	1.318	1.576
9547	21.4	30.8	25.0	5.8	4.485			
9607	21.5	30.7	25.0	5.7	4.490			
9667	21.5	30.6	25.0	5.5	4.489			
9727	21.5	30.5	25.1	5.4	4.496			
9787	21.5	30.3	25.1	5.3	4.491			
9847	21.4	30.2	25.1	5.2	4.500			
9907	21.4	30.2	25.1	5.1	4.512			
9967	21.4	30.1	25.1	5.0	4.502			
10027	21.4	30.0	25.1	4.9	4.510			
10031	21.4	30.0	25.1	4.9	4.514	4.231	1.326	1.579
10035	21.3	31.2	24.9	6.3	4.593	4.296	1.348	1.600
10095	21.4	31.1	24.9	6.2	4.575	4.311	1.361	1.589
10155	21.4	31.2	24.9	6.2	4.588	4.325	1.356	1.613
10215	21.4	30.9	25.0	6.0	4.608			

TABLE III CREEP TEST #7.5

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL POT	AXIAL GAUGE	DIAM GAUGE	VOL GAUGE
mins	deg C	MPa	MPa	MPa	ms	ms	ms	ms
10275	21.4	30.8	25.0	5.8	4.607			
10335	21.4	30.6	25.0	5.7	4.626			
10395	21.3	30.5	25.0	5.5	4.625			
10455	21.3	30.4	24.9	5.4	4.627			
10515	21.3	30.2	24.9	5.3	4.627			
10575	21.3	30.2	24.9	5.3	4.621			
10635	21.3	30.0	24.9	5.1	4.621			
10695	21.2	30.0	24.9	5.1	4.621			
10755	21.2	29.9	24.9	5.0	4.626			
10815	21.3	29.8	24.9	4.9	4.618			
10875	21.3	29.7	24.9	4.9	4.623			
10928	21.3	29.7	24.9	4.8	4.630	4.357	1.377	1.603
10931	21.3	31.2	24.9	6.3	4.732	4.423	1.396	1.631
10991	21.3	30.8	24.9	5.9	4.718			
11051	21.3	30.7	24.9	5.8	4.712			
11111	21.3	30.6	24.9	5.6	4.697	4.429	1.408	1.613
11113	21.3	31.1	24.9	6.2	4.713	4.451	1.415	1.621
11173	21.4	30.9	25.0	5.9	4.731	4.455	1.403	1.649
11178	21.3	31.1	25.0	6.2	4.727	4.465	1.404	1.657
11238	21.4	30.9	25.0	6.0	4.732	4.470	1.409	1.652
11242	21.4	31.2	24.9	6.2	4.735	4.480	1.412	1.656
11302	21.5	31.0	25.0	6.0	4.749			
11362	21.5	30.9	25.0	5.8	4.745			
11422	21.6	30.8	25.1	5.7	4.745			
11482	21.6	30.7	25.1	5.6	4.740			
11483	21.6	30.7	25.1	5.6	4.744	4.491	1.419	1.653
11486	21.6	31.1	24.9	6.2	4.760	4.514	1.430	1.654

TABLE IIIm LOAD TEST #7.6

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT ms	GAUGE ms	GAUGE ms	GAUGE ms
0	21.6	31.1	24.9	6.2	0.000	0.000	0.000	0.000
5	21.6	31.7	24.9	6.8	.038	.041	.011	.019
10	21.6	32.5	24.9	7.5	.095	.092	.032	.028
15	21.6	33.1	24.9	8.2	.163	.149	.050	.049
20	21.6	33.6	24.9	8.7	.223	.219	.073	.073
25	21.6	34.2	24.9	9.3	.318	.315	.107	.101
30	21.6	35.0	24.9	10.0	.469	.459	.157	.145
35	21.7	35.4	24.9	10.5	.593	.586	.205	.176
40	21.6	36.1	24.9	11.2	.752	.759	.270	.219
45	21.6	36.9	24.8	12.1	1.048	1.060	.383	.294
50	21.6	37.4	24.9	12.5	1.161	1.180	.432	.316
55	21.6	37.9	24.9	12.9	1.327	1.364	.495	.374
60	21.6	38.5	24.9	13.6	1.577	1.615	.587	.441
65	21.7	39.2	24.9	14.2	1.861	1.899	.688	.523
70	21.7	39.8	24.9	14.9	2.152	2.198	.810	.578
75	21.7	40.4	24.9	15.5	2.482	2.539	.930	.679
80	21.7	41.0	24.9	16.1	2.830	2.870	1.060	.750
85	21.7	41.1	24.9	16.2	3.038	3.088	1.139	.810
90	21.7	42.2	24.9	17.3	3.507	3.566	1.338	.890
95	21.7	42.9	24.9	18.0	3.946	4.040	1.497	1.046
100	21.7	43.4	24.9	18.5	4.381	4.448	1.681	1.086
105	21.7	44.0	24.9	19.1	4.919	4.970	1.872	1.226
110	21.7	44.5	24.9	19.6	5.362	5.429	2.066	1.297
115	21.7	45.3	24.9	20.4	5.896	6.005	2.276	1.453
120	21.7	45.9	24.9	20.9	6.452	6.523	2.511	1.501
125	21.7	46.4	24.9	21.5	7.026	7.123	2.735	1.653
130	21.7	47.1	24.9	22.2	7.622	7.691	2.995	1.701
135	21.8	47.7	24.9	22.7	8.258	8.602	3.240	2.122
140	21.8	48.3	24.9	23.4	8.955	9.020	3.545	1.930
145	21.8	48.9	24.9	24.0	9.599	9.718	3.808	2.102
150	21.8	49.5	24.9	24.6	10.321	10.441	4.153	2.135
155	21.8	50.1	24.9	25.2	11.063	11.188	4.438	2.312
160	21.8	50.8	24.9	25.9	11.866	11.947	4.801	2.345
165	21.8	51.5	24.9	26.6	12.672	12.844	5.150	2.544
170	21.8	51.9	24.9	27.0	13.516	13.618	5.540	2.538
175	21.8	52.5	25.0	27.5	14.357	14.512	5.896	2.720
180	21.8	53.1	24.9	28.2	15.224	15.361	6.338	2.685
185	21.8	53.7	24.9	28.8	16.177	16.371	6.728	2.915
190	21.8	54.3	24.9	29.4	17.158	17.284	7.192	2.900
195	21.8	54.9	24.9	30.0	18.172	18.360	7.627	3.106
200	21.8	55.6	24.9	30.7	19.266	19.422	8.160	3.102
205	21.9	56.1	24.9	31.2	20.460	20.708	8.688	3.332
210	21.9	56.7	24.9	31.8	21.647	21.813	9.256	3.301

TABLE IIIm LOAD TEST #7.6

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL POT	AXIAL GAUGE	DIAM GAUGE	VOL GAUGE
mins	deg C	MPa	MPa	MPa	ms	ms	ms	ms
215	21.9	57.2	24.9	32.3	22.892	23.110	9.790	3.530
220	21.9	57.9	24.9	33.0	24.168	24.291	10.424	3.443
225	21.9	58.3	24.9	33.4	25.505	25.725	11.002	3.721
230	21.9	59.0	24.9	34.1	26.961	27.028	11.722	3.584
235	21.9	59.6	24.9	34.7	28.449	28.612	12.381	3.850
240	21.9	60.2	24.9	35.3	30.126	29.004	13.216	2.572
245	21.9	60.7	24.9	35.8	32.309		13.909	
250	21.9	61.3	24.9	36.4	34.822		14.730	
255	21.9	62.1	24.9	37.2	37.553		15.606	
260	21.9	62.5	24.9	37.5	40.309		16.554	
265	21.9	63.2	24.9	38.3	42.803		17.521	
270	21.9	63.9	24.9	39.0	45.375		18.582	
275	21.9	64.4	24.9	39.5	48.067		19.666	
280	21.9	65.0	24.9	40.1	50.785		20.860	
285	21.9	65.6	24.9	40.7	53.223		22.223	
290	21.9	66.1	24.9	41.2	56.577			
295	22.0	66.8	24.9	41.9	60.040			
300	22.0	67.4	24.9	42.5	63.749			
305	22.0	67.9	24.9	42.9	67.474			
310	22.0	68.5	24.9	43.6	71.517			
315	22.0	69.0	24.9	44.1	75.097			
320	22.0	69.5	24.9	44.6	77.705			
325	22.0	71.0	24.9	46.1	81.032			
330	22.0	72.2	25.0	47.3	85.483			
335	22.0	73.6	24.9	48.7	90.599			
340	22.0	74.8	24.9	49.9	96.034			

TABLE II In LOAD TEST #8.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C	MPa	MPa	MPa	MPa	POT	GAUGE	GAUGE
						ms	ms	ms
0	21.1	10.2	9.9	.3		0.000	0.000	0.000
11	21.1	10.6	9.9	.7		.129	.032	.065
13	21.1	11.4	9.9	1.5		.162	.040	.082
15	21.1	12.1	9.9	2.2		.186	.049	.088
17	21.1	12.6	10.0	2.7		.241	.057	.128
19	21.1	13.2	10.0	3.3		.317	.068	.182
21	21.1	13.9	10.0	3.9		.424	.092	.240
23	21.1	14.5	10.0	4.5		.566	.118	.331
25	21.1	15.1	10.0	5.1		.735	.153	.430
27	21.1	15.7	10.0	5.8		.921	.190	.541
29	21.1	16.2	9.9	6.3		1.142	.242	.659
31	21.1	17.0	10.0	7.0		1.379	.296	.787
33	21.1	17.4	10.0	7.5		1.623	.356	.911
35	21.1	18.1	10.0	8.1		1.895	.416	1.063
37	21.1	18.6	10.0	8.7		2.179	.497	1.186
39	21.1	19.3	10.0	9.3		2.539	.580	1.379
41	21.2	19.9	10.0	10.0		2.846	.661	1.524
43	21.2	20.5	10.0	10.6		3.231	.770	1.692
45	21.1	21.3	10.0	11.3		3.614	.884	1.847
47	21.1	21.7	10.0	11.8		3.987	.990	2.008
49	21.2	22.2	10.0	12.3		4.335	1.093	2.150
51	21.2	23.0	10.0	13.0		4.782	1.227	2.328
53	21.1	23.6	10.0	13.6		5.196	1.359	2.479

TABLE IIo LOAD TEST #8.2

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL POT	AXIAL GAUGE	DIAM GAUGE	VOL GAUGE
mins	deg C	MPa	MPa	MPa	ms	ms	ms	ms
0	21.2	10.1	10.0	.1		0.000	0.000	0.000
5	21.2	11.7	10.0	1.7		.065	.012	.041
10	21.2	43.6	10.0	3.2		.154	.037	.081
15	21.2	14.8	10.0	4.8		.238	.055	.129
20	21.2	16.4	10.0	6.4		.348	.082	.185
25	21.2	18.0	10.0	8.0		.473	.115	.243
30	21.2	19.3	10.0	9.3		.632	.159	.315
35	21.2	20.8	10.0	10.9		.887	.234	.419
40	21.2	22.4	10.0	12.5		1.301	.371	.560
45	21.2	23.9	10.0	13.9		1.977	.604	.770
50	21.2	25.4	10.0	15.4		2.855	.914	1.028
55	21.2	26.9	10.0	16.9		4.014	1.343	1.328
60	21.2	28.5	10.0	18.6		5.138	1.794	1.550
65	21.2	30.1	10.0	20.1		6.464	2.327	1.810
70	21.2	31.5	10.0	21.5		7.799	2.904	1.991
75	21.2	33.4	10.0	23.4		9.387	3.585	2.218
80	21.2	34.5	10.0	24.5		11.126	4.381	2.364
85	21.2	36.3	9.9	26.4		13.100	5.271	2.558
90	21.2	37.5	10.0	27.5		14.929	6.179	2.572
95	21.2	39.3	10.0	29.3		17.243	7.303	2.638
100	21.2	40.6	10.0	30.6		19.754	8.596	2.562
105	21.3	42.2	9.9	32.3		22.315	9.845	2.626
110	21.3	43.6	10.0	33.6		25.245	11.453	2.339
115	21.3	45.2	10.0	35.2		29.233	13.541	2.151
120	21.2	46.7	10.0	36.7		32.653	15.447	1.759
125	21.2	48.6	9.9	38.7		37.903	18.291	1.321

TABLE IIp LOAD TEST # 9.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	GAUGE
					ms	ms	ms	ms
0	21.4	10.3	9.9	.3	0.000	0.000	0.000	0.000
5	21.3	11.8	9.9	1.9	.110	.188	.036	.116
10	21.3	13.2	10.0	3.3	.466	.381	.079	.223
15	21.4	14.8	9.9	4.9	1.031	.796	.151	.494
20	21.4	16.3	10.0	6.3	1.723	1.810	.239	1.332
25	21.4	17.6	10.0	7.6	2.528	2.400	.387	1.626
30	21.4	19.3	10.0	9.4	3.542	3.094	.568	1.958
35	21.4	21.0	10.0	11.0	4.663	3.970	.781	2.408
40	21.4	22.5	9.9	12.5	6.036	4.593	1.068	2.457
45	21.4	24.0	10.0	14.0	7.403	5.726	1.375	2.976
50	21.4	25.5	10.0	15.6	8.710	6.796	1.730	3.336
55	21.4	27.0	9.9	17.1	10.173	7.942	2.187	3.568
60	21.4	28.6	9.9	18.6	11.868	9.290	2.700	3.890
65	21.4	30.1	9.9	20.2	13.724	10.798	3.304	4.190
70	21.4	31.7	9.9	21.8	15.240	12.044	3.800	4.444
75	21.4	33.0	10.0	23.0	17.079	13.502	4.646	4.210
80	21.4	34.7	10.0	24.7	19.015	15.231	5.462	4.307
85	21.5	36.4	10.0	26.4	21.316	17.063	6.569	3.925

TABLE IIq CREEP TEST #9.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL POT	AXIAL GAUGE	DIAM GAUGE	VOL GAUGE
mins	deg C	MPa	MPa	MPa	ms	ms	ms	ms
	21.5	36.4	10.0	26.4	0.000	0.000	0.000	0.000
5	21.5	36.3	9.9	26.3	.768	.729	.404	-.079
10	21.5	36.3	9.9	26.3	1.483	1.400	.816	-.232
15	21.5	36.2	10.0	26.2	2.068	1.440	1.561	-1.682
20	21.5	36.4	9.9	26.4	2.614	1.815		
25	21.5	36.3	9.9	26.3	3.086	2.141		
30	21.5	36.3	9.9	26.4	3.591	2.333		
35	21.6	36.4	9.9	26.5	4.037	2.512		
40	21.6	36.2	10.0	26.2	4.429	2.731		
45	21.6	36.3	9.9	26.4	4.832	2.982		
50	21.6	36.3	9.9	26.4	5.197	3.202		
55	21.6	36.3	9.9	26.4	5.573	3.382		
60	21.6	36.3	9.9	26.4	5.932	3.583		
65	21.6	36.4	9.9	26.4	6.470	3.787		
70	21.6	36.3	10.0	26.3	6.925	3.993		
75	21.6	36.3	10.0	26.3	7.304	4.034		
80	21.6	36.3	9.9	26.4	7.630	4.051		
85	21.7	36.4	9.9	26.5	7.985	4.123		
90	21.6	36.3	9.9	26.3	8.295	4.149		
95	21.6	36.4	9.9	26.5	8.594	4.180		
100	21.6	36.3	9.9	26.4	8.926	4.312		
105	21.7	36.3	9.9	26.4	9.216	4.464		
110	21.7	36.3	10.0	26.4	9.515	4.629		
115	21.7	36.2	9.9	26.3	9.811	4.726		
120	21.7	36.3	9.9	26.4	10.124	4.837		
125	21.8	36.4	9.9	26.5	10.456	4.938		
130	21.7	36.3	10.0	26.4	10.792	4.986		
135	21.7	36.2	10.0	26.3	11.098	5.028		
140	21.7	36.2	9.9	26.3	11.421	5.156		
145	21.8	36.4	9.9	26.5	11.737	4.275		
150	21.8	36.3	9.9	26.3	12.053	3.878		
155	21.7	36.2	9.9	26.3	12.336	2.956		
160	21.7	36.2	9.9	26.3	12.642	2.877		
165	21.8	36.2	9.9	26.2	12.964	2.881		
170	21.8	36.3	9.9	26.3	13.263	2.909		
175	21.8	36.4	9.9	26.5	13.592	2.945		
180	21.8	36.3	9.9	26.3	13.895	2.972		
185	21.8	36.3	9.9	26.4	14.185	3.036		
190	21.8	36.3	9.9	26.4	14.487	3.048		
195	21.8	36.4	9.9	26.4	14.800	3.072		
200	21.8	36.4	9.9	26.4	15.109	3.097		
205	21.9	36.3	9.9	26.3	15.392	2.826		
210	21.9	36.4	9.9	26.4	15.701	2.634		

TABLE IIq CREEP TEST #9.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C		MPa	MPa	MPa	POT	GAUGE	GAUGE
						ms	ms	ms
215	21.9		36.4	9.9	26.5	16.027	2.562	
220	21.9		36.3	9.9	26.4	16.749	2.590	
225	21.9		36.5	9.9	26.6	16.952	2.313	
230	21.9		36.3	9.9	26.4	17.434	2.351	
235	21.9		36.5	9.9	26.5	17.996	2.507	
240	21.9		36.6	9.9	26.7	18.349	2.023	
245	22.0		36.3	10.0	26.3	18.622	1.730	
250	21.9		36.3	9.9	26.4	18.901	1.525	
255	22.0		36.3	10.0	26.4	19.214	1.463	
260	21.9		36.3	10.0	26.3	19.503	1.394	
265	22.0		36.5	9.9	26.6	19.799	1.274	
270	22.0		36.3	9.9	26.4	20.142	1.351	
275	22.0		36.3	9.9	26.4	20.471	1.247	
280	22.0		36.4	9.9	26.5	20.820	1.139	
285	22.0		36.1	10.0	26.1	21.113	1.048	
290	22.0		36.2	10.0	26.3	21.479	1.131	
295	22.0		36.3	9.9	26.4	21.788	1.113	
300	22.0		36.2	9.9	26.2	22.147	1.039	
305	22.0		36.3	9.9	26.4	22.516	1.097	
310	22.1		36.2	10.0	26.2	22.849	.768	
315	22.1		36.4	9.9	26.4	23.245	.681	
320	22.1		36.2	10.0	26.2	23.621	.525	
325	22.1		36.4	9.9	26.5	24.006	.451	
330	22.1		36.2	9.9	26.3	24.375	.418	
335	22.1		36.5	9.9	26.5	24.811	.296	
340	22.1		36.2	9.9	26.3	25.234	.053	
345	22.2		36.3	9.9	26.4	25.662	-.003	
350	22.1		36.2	9.9	26.3	26.092	-.041	
355	22.1		36.3	9.9	26.4	26.520	-.093	
360	22.1		36.3	9.9	26.3	26.966	-.084	
365	22.1		36.3	9.9	26.4	27.472	-.081	
370	22.1		36.4	9.9	26.5	27.964	-.122	
375	22.2		36.3	9.9	26.4	28.469	-.109	
380	22.1		36.4	9.9	26.5	29.038	-.137	
385	22.2		36.3	9.9	26.4	29.644	-.223	
390	22.2		36.2	9.9	26.3	30.279		
395	22.2		36.4	9.9	26.5	30.974		
400	22.2		36.3	9.9	26.3	31.822		
405	22.2		36.3	9.9	26.4	32.697		
410	22.2		36.3	10.0	26.4	33.941		
415	22.3		35.3	10.1	25.2	37.912		

TABLE IIr LOAD TEST #10.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL POT	AXIAL GAUGE	DIAM GAUGE	VOL GAUGE
mins	deg C	MPa	MPa	MPa	ms	ms	ms	ms
0	22.2	.4	-.1	.5	0.000			
5	22.3	9.7	10.0	-.3	.663			
11	22.5	11.6	10.0	1.6	.669			
14	22.5	11.5	10.0	1.6	.692			
19	22.6	13.1	10.0	3.1	1.255			
24	22.5	14.5	10.0	4.5	1.659			
29	22.6	16.1	10.0	6.1	1.968			
34	21.0	17.2	10.0	7.3	2.403			
39	21.0	19.0	10.0	9.0	2.865			
44	20.9	20.6	10.0	10.6	3.430			
49	21.0	22.1	10.0	12.1	4.107			
54	21.0	23.9	10.0	13.8	4.855			
59	21.0	25.0	10.0	15.0	5.517			
64	21.0	26.3	10.0	16.3	6.354			
69	21.0	27.7	10.0	17.7	7.235			
74	21.1	29.4	10.0	19.4	8.383			

TABLE II's CREEP TEST #10.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	VOL
		MPa	MPa	MPa	ms	ms	ms	ms
0	21.1	29.4	10.0	19.4	0.000			
5	21.0	29.6	10.0	19.6	.352			
13	21.1	29.6	10.0	19.6	.574			
23	21.1	29.6	10.0	19.6	.825			
33	21.1	29.6	10.0	19.6	1.001			
43	21.1	29.6	10.0	19.6	1.156			
53	21.1	29.6	10.0	19.6	1.261			
63	21.1	29.7	10.0	19.7	1.397			
73	21.2	29.6	10.0	19.6	1.482			
83	21.2	29.6	10.0	19.6	1.588			
93	21.2	29.6	10.0	19.6	1.668			
103	21.2	29.7	10.0	19.7	1.756			
113	21.2	29.4	10.0	19.4	1.814			
133	21.3	29.6	10.0	19.6	1.980			
163	21.3	29.5	10.0	19.5	2.144			
193	21.3	29.1	10.0	19.1	2.235			
223	21.4	29.4	10.0	19.4	2.372			
253	21.4	29.7	10.0	19.6	2.577			
283	21.4	29.3	10.0	19.3	2.663			
313	21.5	29.5	10.0	19.5	2.782			
343	21.5	29.2	10.0	19.2	2.871			
373	21.5	29.5	10.0	19.6	2.980			
403	21.5	29.3	10.0	19.3	3.044			
433	21.6	29.3	9.9	19.3	3.111			
463	21.6	29.6	10.0	19.7	3.221			
509	21.6	29.5	10.0	19.5	3.338			
539	21.6	29.1	10.0	19.1	3.375			
569	21.6	29.4	10.0	19.4	3.443			
599	21.6	29.3	10.0	19.3	3.505			
629	21.7	29.3	10.0	19.3	3.577			
659	21.7	29.3	10.0	19.3	3.642			
689	21.7	29.3	10.0	19.3	3.695			
719	21.7	29.2	10.0	19.2	3.743			
749	21.7	29.5	10.0	19.5	3.821			
779	21.7	29.4	10.0	19.4	3.884			
809	21.7	29.3	10.0	19.4	3.951			
839	21.7	29.4	10.0	19.4	4.016			
869	21.8	29.2	10.0	19.3	4.064			
899	21.8	29.4	10.0	19.4	4.129			
929	21.8	29.4	10.0	19.4	4.188			
959	21.8	29.4	10.0	19.4	4.247			
989	21.8	29.3	10.0	19.3	4.298			
1019	21.8	29.4	10.0	19.4	4.349			

TABLE II's CREEP TEST #10.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL POT	AXIAL GAUGE	DIAM GAUGE	VOL GAUGE
mins	deg C	MPa	MPa	MPa	ms	ms	ms	ms
1105	21.9	29.6	9.9	19.7	4.541			
1165	21.9	29.5	10.0	19.5	4.610			
1225	21.9	29.6	9.9	19.6	4.738			
1285	21.8	29.5	10.0	19.5	4.838			
1345	21.9	29.7	9.9	19.7	4.926			
1405	21.9	29.5	9.9	19.5	5.005			
1465	21.9	29.4	10.0	19.4	5.105			
1525	22.0	29.3	10.0	19.3	5.164			
1585	22.0	29.4	10.0	19.5	5.263			
1645	22.0	29.6	10.0	19.6	5.379			
1705	22.1	29.4	9.9	19.5	5.466			
1765	22.1	29.5	10.0	19.6	5.549			
1825	22.1	29.5	9.9	19.6	5.628			
1885	22.1	29.4	9.9	19.5	5.693			
1945	22.1	29.3	9.9	19.4	5.752			
2005	22.1	29.4	10.0	19.4	5.821			
2065	22.2	29.2	10.0	19.2	5.901			
2125	22.2	29.3	10.0	19.4	5.971			
2185	22.2	29.0	10.0	19.0	6.028			
2245	22.3	29.3	10.0	19.3	6.091			
2305	22.3	29.5	9.9	19.5	6.172			
2366	22.3	29.4	10.0	19.5	6.241			
2425	22.4	29.4	10.0	19.4	6.300			
2485	22.4	29.6	9.9	19.6	6.377			
2605	22.5	29.6	10.0	19.6	6.525			
2785	22.6	29.4	10.0	19.5	6.729			
2966	22.7	29.6	10.0	19.6	6.926			
3145	22.9	29.4	10.0	19.4	7.123			
3325	22.9	29.4	10.0	19.4	7.306			
3505	23.0	29.1	10.0	19.1	7.431			
3685	23.0	29.2	10.0	19.2	7.563			
3865	22.9	29.4	9.9	19.5	7.718			
4045	22.9	29.5	10.0	19.6	7.905			
4225	23.0	29.7	10.0	19.7	8.107			
4405	23.0	29.7	10.0	19.7	8.274			
4585	23.1	29.8	10.0	19.7	8.468			
4765	23.2	29.6	10.0	19.6	8.632			
4945	23.1	29.6	10.0	19.6	8.762			
5125	23.0	29.6	10.1	19.5	8.908			
5305	22.9	29.5	10.1	19.4	9.007			
5485	22.9	29.6	10.0	19.6	9.131			
5665	22.9	29.3	10.0	19.3	9.239			
5845	22.9	29.5	10.0	19.5	9.352			
6025	23.0	30.2	10.1	20.0	9.608			

TABLE II: CREEP TEST #10.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
		CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	VOL
					ms	ms	ms	GAUGE
								ms
6205	23.0	29.9	10.0	19.9	9.793			
6385	22.9	29.9	10.0	19.9	9.989			
6565	22.8	29.6	10.0	19.5	10.122			
6745	22.6	29.5	10.0	19.4	10.209			
7015	22.5	29.5	10.0	19.5	10.357			
7375	22.6	29.6	10.1	19.5	10.600			
7735	22.7	29.8	10.0	19.8	10.886			
8095	22.5	29.6	10.1	19.5	11.079			
8455	22.2	29.7	10.0	19.7	11.285			
8815	22.2	29.6	10.0	19.5	11.487			
9175	22.3	29.9	10.0	20.0	11.739			
9535	22.2	29.8	10.1	19.7	12.010			
9895	22.1	29.7	10.0	19.7	12.175			
10255	22.3	29.5	10.0	19.5	12.331			
10615	22.4	29.7	10.0	19.7	12.512			
10975	22.2	29.6	10.1	19.6	12.660			
11333	22.3	29.7	10.1	19.6	12.840			
11693	22.5	29.6	10.0	19.5	13.023			
12053	22.6	29.3	10.2	19.1	13.147			
12413	22.4	29.3	10.2	19.1	13.243			
12773	22.4	29.4	10.0	19.3	13.407			
13133	22.7	29.3	10.1	19.2	13.542			
13493	22.8	29.7	10.0	19.6	13.729			
13853	22.8	29.4	10.2	19.2	13.843			
14393	22.8	29.7	10.0	19.7	14.147			
15113	22.5	29.6	10.0	19.6	14.495			
15833	22.1	29.6	10.0	19.6	14.759			
16553	21.9	29.8	10.0	19.8	15.079			
17273	21.8	29.8	10.0	19.8	15.400			
17993	21.8	29.5	10.0	19.5	15.646			
18713	21.6	30.0	10.0	20.0	16.032			
19433	21.7	29.4	10.2	19.3	16.325			
20153	21.7	30.0	9.9	20.0	16.726			
20873	21.5	29.9	10.0	19.9	17.076			
21593	21.1	29.8	10.0	19.8	17.355			
22313	21.0	30.0	9.9	20.0	17.681			
23033	20.9	30.0	9.9	20.0	17.940			
23753	20.8	29.9	10.0	19.9	18.210			
24473	20.7	29.8	9.9	19.8	18.419			
25193	21.0	29.7	10.0	19.7	18.645			
25913	21.0	29.8	10.0	19.9	18.861			
26633	21.6	29.4	10.2	19.2	19.062			
27353	21.8	29.8	10.0	19.8	19.399			
28073	22.0	29.5	10.0	19.5	19.660			

TABLE IIa CREEP TEST #10.1

TIME	TEMP	AVERAGE STRESS			AVERAGE STRAIN			
	CELL	AXIAL	CONF	DEV	AXIAL	AXIAL	DIAM	VOL
mins	deg C	MPa	MPa	MPa	POT	GAUGE	GAUGE	GAUGE
					ms	ms	ms	ms
29153	22.2	29.6	10.0	19.6	20.069			
30593	22.5	29.2	10.0	19.2	20.472			
32033	22.5	29.8	10.0	19.8	20.933			
33473	22.1	29.8	10.0	19.8	21.388			
34913	21.8	29.8	10.0	19.8	21.824			
36353	21.6	29.8	9.9	19.9	22.252			
37793	21.2	29.7	10.0	19.8	22.644			
39233	21.1	29.9	9.9	19.9	23.035			
40673	21.0	29.8	9.9	19.9	23.460			
42113	20.9	29.7	9.9	19.8	23.807			
43553	20.9	29.9	9.9	20.0	24.169			
44993	20.8	29.8	9.9	19.8	24.509			
46433	20.7	29.8	9.9	19.8	24.842			
47873	20.8	29.5	10.0	19.5	25.140			
49313	20.9	29.5	10.0	19.6	25.454			
50753	20.9	29.9	9.9	20.0	25.836			
52193	21.0	29.9	9.9	20.0	26.205			
53633	21.1	29.6	9.9	19.7	26.533			
55073	21.3	29.8	9.9	19.9	26.859			
56513	21.2	29.7	9.9	19.7	27.189			
57953	21.2	29.7	9.9	19.8	27.510			
59393	21.2	29.6	9.9	19.7	27.826			
60833	21.2	29.8	9.9	19.9	28.181			
62273	21.3	29.7	9.9	19.9	28.526			
63713	21.2	29.7	9.9	19.8	28.840			
65153	21.0	29.8	9.9	19.9	29.179			
66593	20.9	29.8	9.9	19.9	29.511			
68033	20.9	29.9	9.9	20.0	29.906			
69473	20.9	29.9	9.9	20.0	30.268			
70913	21.0	30.0	9.9	20.0	30.688			
72353	21.2	29.9	9.9	20.0	31.072			
73793	21.2	30.0	9.9	20.2	31.469			
75233	21.3	30.0	9.9	20.1	31.885			
76673	21.2	29.9	9.9	20.0	32.243			
78113	21.2	29.9	9.9	20.0	32.606			
79553	21.3	29.8	9.9	19.9	32.969			
80993	21.2	30.0	9.9	20.2	33.429			
82433	21.1	30.0	9.9	20.2	33.829			
83873	21.0	30.0	9.9	20.1	34.260			
85313	21.1	30.0	9.9	20.1	34.679			
86753	21.0	29.9	9.9	20.0	35.035			
88193	21.0	29.9	9.9	20.0	35.418			
89633	21.0	29.9	9.9	20.1	35.825			
91073	20.9	29.9	9.9	20.0	36.183			